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Volume 2. Contract Papers
Part E: Valuation of Biological Diversity

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TECHNOLOGIES TO MAINTAIN BIOLOGICAL DIVERSITY

Volume II--Contract Papers

Part E: Valuation of Biological Diversity

1. An Economic Perspective of the Valuation of Biological Diversity
   (Alan Randall)
2. Values and Biological Diversity
   (Bryan G. Norton)
3. An Ecological Perspective on the Valuation of Biological Diversity
   (Gordon Orians and William Kunin)
4. Critical Assessment of the Value of and Concern for the Maintenance of Biological Diversity
   (Malcolm F. McPherson)

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December 1986

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Contract Paper No. 1

An Economic Perspective of the Valuation of Biological Diversity

Alan Randall
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October 1985

Office of Technology Assessment
U.S. Congress

This contract paper was prepared for the assessment of "Technologies to Maintain Biological Diversity." The views expressed are those of the author(s) and not necessarily those of OTA.

AN ECONOMIC PERSPECTIVE ON BIOLOGICAL DIVERSITY

Alan Randall

A final report submitted to:

Congress of the United States

Office of Technology Assessment

September 1985

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AN ECONOMIC PERSPECTIVE ON THE VALUATION OF BIOLOGICAL DIVERSITY

Alan Randall

Economics, as a discipline, has its roots in moral philosophy. In the English-language literature, the roles of David Hume, Adam Smith, Jeremy Bentham and John Stuart Mill as important philosophers and seminal economists are sufficient to establish this point.

With its roots in philosophy, economics is not captive to any single philosophical perspective (Randall 1985a). Nevertheless, there is a mainstream in economics that has developed an elaborate structure by pursuing at length the implications of particular formulations of utilitarianism, at the individual and collective levels.

This essay will examine the concept of valuation, as developed by this mainstream in economics, and explore its implications for biological diversity.

1. Individual Utility and Values Attributable to Biological Diversity

Economists assume the individual has a utility function which expresses individual preferences across the array of alternatives. The utility function should satisfy certain logical restrictions, but the preferences it expresses may cover the full range of human concerns. Modern formulations (for example, those that derive from the household production function and human capital theory) explicitly allow learning processes, information and the conscious acquisition of skills to appreciate and use various items to influence preferences. Thus, I argue

that people come by their preferences in a serious manner, reflecting cultural traditions, individual learning and experiences and a good deal of introspection. Personal preferences fall short of general ethical principles but, in the absence of universally accepted ethical principles incumbent on all persons, personal preferences have some moral force. Economics assumes that what the individual wants is good for the individual.[1]

The notion of preferences concerning biological diversity explicitly treats biotic resources as instruments for human satisfaction. It is explicitly instrumentalist, utilitarian and homocentric. There may be other views of the role of non-human life-forms (e.g., they may be seen as "having a good of their own", possessing rights, or being the beneficiaries of duties and obligations arising from ethical principles incumbent on humans). Some people, including some people who are economists, may subscribe to some of these views. Nevertheless, my purpose in developing the economic perspective is to confine myself to instrumental, utilitarian and homocentric formulations, exploring their implications for valuation. Implications of other approaches will, on their own merits, provide perspectives additional to those offered here.

The mainstream economic formulation assumes that the individual seeks to maximize utility subject to constraints that each possibility has a cost and the resources that the individual commands are bounded. Individual choices are rational, given individual preferences and constraints.

If humans interact within a system with limited total resources, each seeking to maximize own-utility, complete and ideal markets would allow equilibrium prices to emerge for all commodities, services, amenities and resources. These prices would accurately reflect the marginal relative values of each item: "values in exchange", for sure, but also social

values if the distribution of resources (and rights governing their use) among people is socially acceptable and the nexus between preferences, resources, distribution and values implicit in this model is ethically acceptable. Further, if trade was unrestricted and mediated by these prices, resources would, in general, be efficiently allocated.

Note that prices for biological diversity and its various aspects are included: with complete and ideal markets, prices for these, too, would be revealed to the extent that they are valued as instruments for human satisfaction. The absence of such prices is due to various departures from ideal markets (Section 3, below), and is an impediment to identifying the relative economic values of biotic resources, but by no means prohibitive thereof. Here lies the distinction between economic values and commercial values: the essential premises for economic valuation are the utility function and scarcity; organized markets are essential only to commerce. It is a fundamental mistake to assume economics is concerned only with the commercial.

Prices and Value

With ideal markets, resources are efficiently allocated and prices reflect value at the margin. For changes that are greater than marginal, value is defined as economic surplus. There is a massive literature defining economic surplus concepts, relating them to market demands, and proposing analytical techniques to generate ideal measures from various kinds of data. Much of this literature is summarized and related to valuation of wildlands resources in Peterson and Randall (1984, Chapters 1,2 and 4). Major conclusions are: Hicksian compensating measures of economic surplus are appropriate for evaluating policy changes; for the

individual, these measures are identical to willingness-to-pay (WTP) for desired policy changes and willingness-to-accept (WTA) undesired but compensated changes, in a market context, these measures are identical to buyer's best offer and seller's reservation price, respectively, in a market context; at the margin in equilibrium, price is equal to WTP and WTA; for homogeneous goods that are traded in very large competitive markets with very low transactions costs, price multiplied by quantity change is a good approximation of WTP or WTA; and where these last-mentioned conditions do not hold, valid valuation requires explicit implementation of the Hicksian compensating measures of WTP and WTA, as appropriate.

Components of Economic Value

Economists distinguish between values that arise from use and those that arise from the mere knowledge that something (e.g., a species, or an ecosystem) continues to exist. Randall (1985b) makes the distinction on the following basis: Use is involved if the biotic resource is combined with other goods or services to generate utility. For example, standing timber may be combined with logging and milling services to produce lumber, which is combined with .... to produce housing services that generate utility; a wildlands site may be combined with travel services and recreationl equipment to produce a recreational visit that generates utility.

Existence is involved if the biotic resource generates utility without being "used", i.e., combined with any other goods or services.

The following categorization of value components is widely accepted among economists, and is adaptable to biotic resources.

1. Use Value is economic value derived from using the ecosystem in any way: as a source of raw materials, medicinal products, aesthetic

satisfaction, personally experienced and vicarious adventure, etc. Thus, use values may be derived from commercial and non-commercial uses, from "consumptive" and "non-consumptive" uses, from on-site and off-site uses. Referring to the Taxonomy of Values (Statement of Work), note that the first three major categories of value -- Economic/Utilitarian, Recreational/Aesthetic and Scientific/Educational -- are clearly use values. The fourth category (Ecological/Evolutionary) has a major use value component, since these things affect the capacity of the environment to provide services now and in the future. Even the Sociological/Historical/Spiritual/Religious values have a substantial use value component.

We identify four components of use value.

a) Current Use Value is generated by current use.

b) Future Use Value is expected to be generated by use in the future.

The distinction between current and future use value is not conceptually important, but has implications for measurement: past and current use is ex post and (for some uses) is routinely recorded and available as secondary data; while future use is ex ante and probabilistic, and subject to change as conditions change in unexpected ways. Future use must be projected from past use or inferred from, e.g., survey data stating the ex ante intentions of the identifiable user population. The uncertainty of future use leads to two kinds of option values.

c) (Ordinary) Option Value: When risk attends the demand for future use and/or the future availability of biotic resources, risk averse users may apply risk premia and discounts. For example, a certain future demander facing uncertain supply may rationally pay a premium to secure an option that guarantees future supply: hence the concept of option value.

The problem is that uncertainty may cut both ways: a risk averse and uncertain demander may expect a discount (not a premium) to compensate for the risk that a purchased option may go unused. In general, then option value may be positive or negative (Schmalensee 1972). Option value is unambiguously non-negative only in some specialized cases, a well-known case being that of certain demand and uncertain supply (Bishop 1982).

The concept of option price (OP), which is equal to the expected value of future use (ES) plus (positive or negative) option value (OV), is generally considered the valid measure of future use value (Bishop 1982) Boyle and Bishop 1985). These constructs, ES, OV and OP, are all based on the notion of sure payments. Building upon the literature on the economics of insurance, Graham (1981) has shown that some schemes of ex post contingent payments may generate values greater than the larger of OP and ES. Graham defines the "fair bet point (FB), which always has an expected value equal to or greater than OP.

It seems clear that FB is the ideal construct for valuing future use. OP can be viewed, quite literally, as the second-best construct, since it is the value at emerges in the absence of perfect contingent claims markets.

d) Quasi-option Value: Arrow and Fisher (1974) and Henry (1974) introduced the concept of quasi-option value, which has special pertinence to preservation vs. development decisions. If development is irreversible (e.g., preservation in period 1 allows the choice of preservation or development in period 2, but development in period 1 pre-ordains development in period 2) and one expects new information about the value of preservation to emerge after period 1 but before the period 2 decision must be made, quasi-option value is positive. It is, essentially the value of the emerging information conditional on having made the period 1 choice

(preservation, in this case) that maximizes the period 2 array of alternatives (Hanemann and Fisher 1984).

Quasi-option value is clearly relevant to biotic resources where, for example, preservation now maintains the possibility that new uses (e.g., medical) may be discovered later, increasing the value of those resources thereafter.

2. Existence Value is derived from the pure knowledge that something (e.g., a biotic resource) continues to exist. Since the concept of existence value is susceptible to misinterpretation, a few clarifying comments may be helpful.[3]

-Existence value for a resource must (in order to distinguish it from use value) be derived without combining it with any other good or service in order to produce any activity other than "just knowing it exists".

-Nevertheless, previous use and the information and appreciation gained from previous use may contribute to current existence value.

-Existence values are not confined to unique natural phenomena threatened with irreversible damage. In principle, anything may have existence value. However, value at the margin depends on demand and supply. It is likely that the existence value, in total, for cattle exceeds that for condors. However, the existence supply of cattle is very large while the supply of condors is quite small. Thus, the loss in existence value from the destruction of a few condors likely far exceeds that from the loss of a few cattle.

Existence values depend on information about the nature of that which exists and its supply situation. Thus, especially for newly discovered and little known species and associations, existence values may be quite volatile as new information changes people's perceptions.

-Since existence values are independent of current use, expected future use, and the avoidance of risks related to future use, they must be derived from some form of caring. Caring could be directed to other people who might use or care about the biotic resource (the philanthropic motive), future generations who might use or care about the resource (the bequest motive), or to the biotic resource itself. The last-mentioned kind of caring generates a form of intrinsic values.[4] These kinds of caring are consistent with the instrumental, utilitarian and homocentric concept of value so long as the valuer is a human who voluntarily values the resource because it pleases him/her to do so. The only kinds of value excluded by this concept are these that arise from duties or ethical obligations imposed upon the human and those that place a non-human entity in the role of valuer.

2. Collective Choice Criteria

Given the concept of individual values developed above, the question remains as to how individual values are expressed in collective choice, (i.e., choice at the level of the society). Three approaches -- individualistic, public interest/social welfare function, and utilitarian/benefit cost -- have been developed in detail by economists.

Individualism

Modern individualism, as expressed by, for example, the political economist James Buchanan, (e.g., 1977) emphasizes Pareto-safety in economics and in politics. Pareto-safety is the criterion that no change which harms any individual can be considered an improvement for society. In economic activity, this criterion is satisfied by voluntary exchange among individuals whose expectations are secured by completely specified,

enforced, and transferable property rights (that is, byideal markets). Assuming the individual is the best (the only) judge of his own well-being, we can be assured that no one would voluntarily enter a trade which would make him worse-off. Under individualism, the value indicators are buyers' best offer (WTP) and seller's reservation price (WTA).

In the political sphere, Pareto-safety means that a proposed change must enjoy unanimous consent if it is to be implemented. The idea of the "general will" is explicitly denied. All that matters is the individual, and no individual should be coerced into accepting political change which is not in his interest. Where private action is ineffective and the real choice is between collective political action and no action at all, unanimity may be attained (and collective action thus legitimized) by compensating those who would otherwise lose and therefore be opposed.

The Public Interest and the Social Welfare Function

Public interest theories have their roots in Rousseau's concept of the social contract: Governments expressing the "general will" must legislate only laws which are addressed to the common good of the society's members and which extend the same rights to and impose the same duties on each citizen.

Modern public interest theories of government express faith that deliberative bodies are capable of identifying and interpreting the general will and of establishing policies and programs to implement it. To promote the general will over the interests of a powerful but selfish few, some considerable regulation of individual activities for the "public health, welfare, safety, and morals" may be justified. There is no need to minimize the scope of government, so long as government serves the

interests of the general public. Thus, programs to promote economic activity, to rectify "market failure" (i.e., to internalize externalities and to provide public goods and "merit" goods), and to promote equality of economic opportunity may all be seen as enhancing the general welfare and thus within the purview of government. Some conflict between individual aspirations and the general will is inevitable, but public interest theorists hope that individuals will be adequately protected by constitutional procedures and majority institutions.

In mainstream economics, public interest and general will notions are expressed in the concept of the social welfare function, which provides a unique and unambiguous ranking of social states (Bergson 1937, Samuelson 1947). Thus assuming individual aspirations sometimes come into conflict, a social welfare function must specify the social consensus as to which kinds of individuals count how much. Formally, the social welfare function is expressed $W = W[U_1(\ ), U_2(\ ),\ldots,U_n(\ )]$, i.e., a mathematical function of individual utility functions. In practice the social welfare function is empirically elusive while there is much controversy, at the theoretical level, about the possibility of its existence (Arrow 1951).

Utilitarianism, the Potential Pareto-Improvement and the Benefit Cost Criterion

The early utilitarian concept that those collective actions should be taken which would produce "the greatest good for the greatest number" finds modern expression in the potential Pareto-improvement (PPI) criterion. If the gainers from some proposed action could compensate those who would otherwise lose, the PPI criterion would find that action acceptable, even if compensation did not actually occur. Thus, the value indicators (WTP and WTA) are those that would emerge from individualistic voluntary

exchange, but the individual protection of Pareto-safety was held to be unnecessary.

The benefit cost criterion (that the benefits of change should exceed the costs, to whomsoever they accrue) is widely argued to be identical with the potential Pareto-improvement (e.g., Peterson and Randall, Chapters 1,2 and 3). Benefit cost analysis (BCA) is an empirical test for potential Pareto-improvements.

The benefit cost criterion provides no security for the individual. If this were to become the sole and universal criterion for collective decisions, individual rights would be completely subordinated to the overall good of the collective. Resource reallocation could then legitimately proceed with government taking from the inefficient and giving to the efficient (as opposed to the exchange process in which the efficient purchase those resources from the less efficient). Thus, philosophical individualists would be implacably opposed to such a collective decision rule. They favor efficiency, of course, but prefer that it emerge spontaneously from individual transactions rather than be deliberately imposed by governments armed with benefit cost analysis.

Public interest theorists would be little happier with such a decision rule, since it would enshrine a narrow, unidimensional concept of the public interest. Surely the general will is broader than that. Economists of the social welfare function school find the benefit cost criterion unduly restrictive. That criterion can be interpreted as one very specific social welfare function: one in which money endowments are substituted for utility and all dollars are weighted equally regardless of the

circumstances of their owners. Few who defend the social welfare function concept would consider this the only acceptable form for the social welfare function.

Thus the benefit cost criterion, unqualified by additional protections under law, is unacceptable to philosophical individualists, adherents of the public interest and social welfare function schools, and (for that matter) a good many utilitarians. Perhaps that is why the benefit cost criterion is seldom used as the basic public decision rule. When it is used at all, it is invariably superimposed on the body of existing law which in the United States bows in the direction of individualism (e.g., by codifying private property rights) and the public interest (e.g., by regulating private activities so as to protect the public health, welfare, safety, and morals).[5] More commonly, benefits and costs become desiderata in the choice from a set of alternatives which satisfy the basic law of the land.

In 1981, the Office of the President, via Executive Order 12,291, required that regulatory initiatives (newly proposed programs and those due for reauthorization) be subject to BCA, with a view to eliminating those which fail the benefit cost test. This attempt to elevate the benefit cost criterion in the public decision process has precipitated legal battles between the legislative and executive branches and philosophical debates between adherents of the potential Pareto-improvement and public interest schools.

3. Value Recognition and Expression in the Market

Biological diversity is a broad concept, encompassing: the preservation of species and of a wide variety of ecosystems and associations of species; maintenance of ecological processes; and sustainable use of species and ecosystems. From the economic perspective, there are two constellations of reasons why the value of biological diversity may be inadequately recognized and expressed in markets: inadequate information and incomplete markets.

The Information Base for Valuation

Biotic resources are valued by people because they contribute directly to human satisfaction, or because they play an important role in the life support systems of species that do. Valuations depend crucially on information and knowledge. Individuals place no value on resources of whose existence or usefulness they are entirely unaware. As information (of varying degrees of reliability) is acquired, valuations may be quite volatile. Eventually, as knowledge of consequences become more complete, valuations tend to stabilize and to reflect more accurately the individual's underlying preferences and endowments.

The information base for valuation of species is very weak. Perhaps seventy percent of the earth's species are as yet uncataloged. For many species that are known, we have little appreciation of their role in life support systems or the services they might provide directly to human. The multiplicity of direct and indirect services provided by those species that have been carefully studied suggests that the biota contains much of value that we do not yet know about. Finally if we seek to evaluate not so much

species per se as policies to protect them, we need information about crucial relationships within the system (i.e., the production possibilities). What environmental conditions (including other species) must be maintained, assure the survival of species X? How large must its range be? How can we be sure not to tip the delicate balance inadvertently in favor of its predators of competitors? If species X is saved what might inadvertently be saved, or lost, as a result? Can the ecosystem survive the loss of some species? If so, how many may be lost before total collapse? Are all species equally crucial to the survival of the ecosystem or, if the ecosystem's survival is the goal, are some species more expendable than others? I don't mean to imply that nothing is known about these things.[6] However, there is much that remains unknown, and it is reasonable to expect valuations to change as more information becomes available.

Incomplete Markets

The ability of complete and ideal markets to efficiently allocate resources and generate prices that reveal the relative marginal values of things has been noted above. Further, it is now possible to use market observations to approximate WTP and WTA (Willig 1976, Randall and Stoll 1980) or to calculate WTP and WTA exactly (Vartia 1983, Bergland and Randall 1984). If markets are incomplete, however, prices and market demands are misleading or unrevealing about economic values.

For some important categories of things people care about, markets are limited and there is only a weak basis for faith in their performance. Nonrivalry, nonexclusiveness, and decisions involving very long time

horizons, for example, introduce major impediments to the functioning of markets. Unfortunately, these difficulties are endemic to biological diversity issues:

(1) As opposed to ordinary (rival) goods, where for a given level of output more for one person necessarily means less for others, the pure existence of biotic resources is a nonrival good. Once existence has been provided, there is no meaningful sense in which it must be divided up among individual "consumers" of preservation: Once provided, it is effectively provided for all. Nonrivalry is not confined to existence; it is also a characteristic of some (but not all) uses.

(2) The existence of biotic resources is usually a nonexclusive good. That is, there is no meaningful way that some people (e.g., those who make no contribution) can be excluded from enjoying the satisfaction of knowing the species survives. Nonexclusiveness applies also to many kinds of uses that may be made of biotic resources. However, some uses that may be made of species (e.g., in the plant breeding, pharmaceutical, and genetic engineering industries) are amenable to exclusive arrangements.

The economic consequences of nonrivalry and nonexclusiveness can be summarized as follows. For things that are nonexclusive, prices tend to approach zero (and, in so doing, understate true scarcity and value) and exploitation tends to be excessive. For things that are exclusive but nonrival, markets may generate some price information but it will be imperfect. That is, prices will not reflect individual WTP and WTA. The value-revealing characteristics of complete and ideal markets require (among other things) that these markets deal in goods that are simultaneously exclusive and rival[7] (Randall 1983).

(3) Since there seems no reasonable prospect of a technology for precisely recreating lost life-forms a brief lapse of vigilance and

commitment to biological diversity could have enormously long consequences. An irreversible loss would be inflicted on every subsequent human generation. Markets, and market-oriented economic theories, tend to treat all intertemporal allocation problems as investment problems. However it is simply not clear that investment logic is adequate to handle issues such as biological diversity where time horizons are very long and losses may be irreversible.

These various "market failures" do not directly threaten the economic concept of value. They do however, generate serious impediments to market revelation of economic values relating to, e.g., biological diversity issues.

Incomplete Markets, Resource Allocation, and Preservation of Biological Diversity

The above discussion has emphasized the role of markets in generating and disseminating information about value. Where property rights and other conditions are conducive, markets serve also to allocate resources to their highest value uses. The two problem-sets discussed above (paucity of information about ecosystem relationships, and incomplete markets for many services provided by biotic resources) limit the capacity of individual decisions, mediated by markets, to allocate biotic resources. With limited effectiveness of private action in efficiently allocating biotic resources, collective and public action may be called for. Unfortunately, as discussed above, the biological and economic information base for such action is problematic.

4. Valuation Criteria and Empirical Methods for Valuation

The economic literature yields two approaches to a valuation and decision system for biological diversity issues: one based on benefit cost analysis (BCA) and one based on the concept of a safe minimum standard (SMS).

The Benefit Cost Analysis Approach

The conceptual framework for BCA is presented, in symbolic terms, as follows.

Consider a complex ecosystem E producing over time a vector of services S(t) valued by people. Suppressing the time dimension, we specify the production system for services as follows:

(1) $S = f(A, Z)$

(2) $A = g(N, X)$

where A: a vector of attributes of the ecosystem,

Z: a vector of human activities,

N: a vector of "natural system inputs", and

X: a vector of human-controlled inputs.

That is, environmental services are produced through the interaction of environmental attributes and human activities that influence, positively or negatively, service production. Attributes are determined through the interaction of human-controlled inputs and the characteristics of the natural system.

Individual utility of j=1,...,m is specified as:

$$(3) \qquad U_j = U_j\,(S_j,\ Z_j),$$

i.e., a function of environmental services and other activities (or to put it in "new demand theory" terms, household-produced commodities). Possible interactions between the S and Z vectors allow for derived (as well as direct) demands for environmental services.

By minimizing expenditures subject to the constraint that utility be maintained at the initial level, the compensated demand system for S can be found and $V_j\,(S_j)$, the value to individual j of S_j, can be calculated.

The value of the ecosystem E, as an asset is the sum across persons of the discounted values of the time stream of services, where r is the rate of interest:

$$(4) \qquad PV\,(E) = \sum_{j=1}^{m} \int_o^{\infty} V_j[S_j(t)]e^{-rt}dt$$

Now consider some program Δ, that would modify the human-controlled inputs, changing X to X^{Δ}. This program would convert the ecosystem E to E^{Δ} at some cost $C^{\Delta}(t)$, replacing the "without program" vector of services S(t) with a "with program" service stream $S^{\Delta}(t)$. The net present value of this program is:

$$(5) \quad PV(\Delta) = PV[(E^{\Delta}-C^{\Delta})-E] = \sum_{j=1}^{m} \int_o^{\infty} \{V_j[S_j^{\Delta}(t)]-C^{\Delta}(t)-V_j[S_j(t)]\}e^{-rt}dt$$

If the present value of this program is greater than zero, its implementation would be a potential Pareto improvement and the program would pass the BC filter.

Implications This concise conceptual framework is fertile with implications for BCA. We enumerate some of these implications.

-BCA is conducted in accordance with the venerable "with and without" principle (equation 5). This involves specifying baseline (i.e., without program) conditions, projecting them through to expected life of the program, and comparing them with projected "with program" conditions.

-The conceptual basis for BCA is the potential Pareto-improvement, PPI, criterion (equations 3, 4). Thus, BCA is a homocentric, utilitarian decision criterion. The value indicators consistent with the PPI are WTP for increments and WTA for decrements in ecosystems services.

-Benefits are conceptualized in total value terms. That is, benefits of a change in service levels from S to S^{Δ} are the total of all use and existence values influenced by that change. It is necessary to inquire directly about total value or to reconstruct total value from a taxonomy of use and existence values each measured in some appropriate way. Randall (1985b), Boyle and Bishop (1985) and Smith (1985) address the difficulties with the "taxonomy of values" approach; and Randall and Boyle and Bishop tentatively endorse a direct total value approach.

-In evaluating proposals concerning biological diversity, many of the components of value are nonexclusive and/or nonrival. This applies to many categories of use value (especially off-site and noncommercial uses) and to existence value. For these cases, nonmarket methods are required to estimate WTP and WTA. If a direct total value approach is used, that too requires nonmarket valuation.

-Equations 1 and 2 specify in general terms the relationships between natural systems, human influence and the production of environmental services. However, the reader should not be misled by the apparent

simplicity of this specification. The dearth of information about key relationships in complex ecosystems (discussed above) poses massive problems for applying BCA to biological diversity issues.

-The key role of the interest rate in BCA (equations 4 and 5) is a major source of concern in applications to biological diversity issues. These issues are paradigm cases of the "very long time horizons" problem to which investment theory may not be well-adapted. Market interest rates reflect the marginal efficiency of investment capital in markets with time horizons ranging from overnight to perhaps thirty years. To this author it is simply not clear that market rates are appropriate for discounting non-marginal events that may have indefinitely-long consequences.

Nonmarket Valuation. The basic value concepts, WTP for benefits and WTA for costs, are well defined and consistent with logic of constrained choice and the PPI criterion. Nevertheless, measurement problems abound and are concentrated in problem situations (such as preservation issues) where nonexclusiveness, nonrivalry, and long time horizons are prevalent. Three basic categories of valuation methods for dealing with these problems are available (Freeman 1979, Peterson and Randall 1984, Anderson and Bishop in press). (1) Where well functioning markets exist and the anticipated quantity changes are small relative to the total quantities in the market, price is an adequate value indicator. Where demand and supply functions can be estimated from market data, these permit approximation of aggregate WTP and WTA even for large quantity changes. (2) For unpriced goods, there may exist closely related goods (complements or substitutes) whose markets can be analyzed to reveal information about the value of the

unpriced good. (3) Hypothetical or experimental markets can be devised for unpriced goods and used in survey or experimental contexts to generate value information.

Each of these methods has its limitations: (1) is inapplicable to many environmental goods; (2) is of broader but nevertheless limited applicability and requires various analytical assumptions which may introduce distortions; (3) is widely applicable, but some commonly used versions are not strictly immune to strategic manipulations on the part of respondents or experimental subjects, while practitioners are still wrestling with the problem of providing experimental subjects and survey respondents with sufficient incentive to consider their responses as carefully as they would "real" economic decisions. Given the present state of the art, only the methods in category (3) can be used to estimate option, quasi-option, and existence values.

Those experienced in development and use of these various methods would claim that each, properly used, generates useful value information. On the other hand, each has its limitations and imperfections. Economists are not free, however, to manipulate value estimates in order to make their (purportedly scientific) conclusions consistent with their personal preferences. The relevant theory and methodological principles are sufficiently well developed to provide the basis for effective criticism. Researchers in the area are constantly pressured to attempt replication and other validation procedures.

In general, as one progresses from current use values to future (potential) use values, option values, and existence values, assessments of consequences and their economic values become less reliable. The difficulties encountered in valuing a single environmental good are

compounded when one moves to valuing the contributions of whole systems. Systems production concepts such as synergism play havoc with the notion of simply adding the contributions of individual components. On the demand side, recent work suggests that valuation of changes in complex systems cannot, in general, proceed via simple summation of the values (or demands) for individual components (Hoehn and Randall 1982).

BCA and Decisions Impacting Biological Diversity. Having explored the potential and the pitfalls of BCA in the preservation of biotic diversity context, I conclude that BCA is likely to provide information useful to the public policy process. The formal procedure of BCA is likely to be helpful for its own sake, since its rigorous structure disciplines investigators who might not otherwise remember to consider all of the relevant variables and their consequences. While BCA will inevitably rely on weakly substantiated data (about consequences and economic values) for some categories of costs and benefits, its capacity to mislead is minimized in an open, critical environment in which benefit cost documents are exposed to professional and public scrutiny.

These observations lead to two caveats. First, there is good reason to be suspicious of any executive agency which treats BCAs as internal documents, shielded from the scrutiny of the public and professionals outside the agency. Such an agency could make honest mistakes. It could also seek to generate public support for programs favored by high-level administrators and those to whom they are responsive, on the (unexaminable and therefore potentially false) grounds that the favored programs provide a superior balance of benefits over costs. Second, inherent data deficiencies provide a pragmatic reason -- in addition to the philosophical reasons -- for objections to the use of the benefit cost criterion as a

strict decision rule (a ranking device or a filter) in preservation issues.

Should economists who seek to provide insight and guidance for public decisions about preservation of biotic resources persevere with BCA? Some (e.g., Smith and Krutilla 1979) argue that the BCA approach is basically appropriate for these kinds of issues. It is almost certain, however, that preservation generates more benefits than can be captured in a BCA. So, it is appropriate to accord the preservation option the benefits of any doubts that remain on completion of the analysis. This approach is designated the "modified BCA" approach.

I am unaware of any complete BCA (or modified BCA) that has been performed at the behest of a public agency to inform the decision process concerning preservation of biological diversity. Nevertheless: the conceptual basis for such studies is in place; examples from other topical areas abound, and could guide efforts concerning preservation issues; and many of the empirical building blocks are becoming available. For example, Stoll and Johnson (1984) report estimates of use, option and existence values for whooping cranes. Similar research concerning other species and associations is in progress at several locations.

The "Safe Minimum Standard" Approach

An alternative approach suggested in writings of the late S.V. Ciriacy-Wantrup and currently promoted by Richard Bishop (1978, 1980) is that of the Safe Minimum Standard (SMS). The SMS is defined as the minimal level of preservation which ensures survival. While Bishop is eloquent in elaborating the beneficial consequences of preservation (or the adverse consequences of failing to ensure the survival of species, habitats, and ecosystems), he resists any obligation to estimate benefits empirically.

For those species not yet screened for commercial use, there is gross uncertainty about the consequences of loss (not mere risk, as the BCA approach implies). Nevertheless, evidence is abundant that the biota in general have provided inestimable subsistence, commercial, and amenity services to humankind. Continuing processes of exploration, investigation, and research frequently reveal new use potentials for species previously thought "useless," and newly understood dependencies of "useful" species and valued ecosystems upon species not previously appreciated by humans. Bishop would take the incontrovertible evidence that species (in the plural) are of high and rising value as a sufficient basis for a presumption of positive value for any single species.

The BCA approach starts each case with a clean slate and painstakingly builds, from the ground up, a body of evidence about the benefits and costs of preservation. The SMS approach starts with a presumption that the maintenance of the SMS for any species is a positive good. The empirical economic question is "can we afford it?" or, more technically, "how high are the opportunity costs of satisfying the SMS?" The decision rule is to maintain the SMS unless the opportunity costs of so doing are intolerably high. The burden of proof is assigned to the case against maintaining the SMS.

The SMS approach avoids some of the pitfalls of formal BCA: e.g., the treatment of gross uncertainty as mere risk, the false appearance of precision in benefit estimation, and the problem of discounting. As opposed to the procedure of discounting, the SMS approach simply accepts that costs may fall disproportionately on present generations and benefits on future generations. Its weakness is that, rather than providing answers, it redefines the question. Nevertheless, an appealing argument

can be made that "can we afford it?", with a presumption in favor of the SMS unless the answer is resounding NO, is the proper question.

Bishop (1980) has compiled several case studies of the opportunity costs of specific preservation decisions. Opportunity costs of preserving California condor habit may exceed $3 million per year. The true costs may be less than that, however, because much of the income forgone is from oil mineral extraction and these reserves may be worth almost as much in the ground as in production. The opportunity costs of preserving the snail darter were probably about zero at the time of the Supreme Court decision, and negative, prior to that time (because the Telico Dam was an economically unattractive project, anyway). Those for saving leopard lizard habitat are also quite low.

The vast majority of endangered species live in tropical environments and there is some concern that a tolerable opportunity cost in the context of the U.S. economy might be an immense burden in many impoverished tropical countries. Bishop, however, reports that the opportunity costs of preserving mountain gorilla habitat in low-income, tropical Rwanda seem to be tolerably low.

These various examples show that the opportunity costs of preservation may often be measured more readily than the benefits. Further, the opportunity costs are not always large, and when they are small that fact alone serves to simplify the decision. Not all preservation decisions are difficult.

The SMS approach differs from the BCA approach in that it starts with a presumption of positive benefits and denies an obligation to document benefits case-by-case. Beyond that, it has much in common with the BCA approach. Were the SMS to be treated as a strict decision rule, it would

be a collective decision rule of the potential Pareto-improvement type. Decisions would be made on the grounds that (presumed) benefits exceed costs in the aggregate, with no particular respect for individual differences in preferences or exposure to costs. As an information system, it offers an argument addressed to societal benefits and a documentation of opportunity costs at the aggregate level. This is useful information to those concerned with broad societal objectives.

Economics as a User of Information from Other Disciplines

The BCA and SMS approaches are "economic", in the sense that they are based on concepts (the PPI, and the concept of opportunity cost) derived directly from standard economic theory. As with much of applied economics, economic theory provides the organizing principles while other disciplines provide much of the information base. To that extent, these methods are interdisciplinary.

To implement the modified BCa and SMS approaches, the opportunity costs of preservation (i.e., the benefits of the best alternative strategy that would be foregone if preservation is chosen) must be estimated. For the BCA approach, the benefits of preservation must also be estimated. Fundamental to benefits (and to opportunity costs, if the best alternative strategy involves sustainable use of natural systems) is information to flesh out the concepts introduced in equations 1 and 2. This information must be generated by the natural sciences and, in the absence of "scientific" data, practicing natural scientists are best-placed to provide educated guesses. Economists are appreciative of this information and respectful of the professional competence of those who provide it. Nevertheless, in this role natural scientists are seen as providers of data

for economists to organize and interpret.

Other Planning Tools

There are a variety of alternative planning, evaluation and decision-making tools that depart, to varying degrees, from economics as the organizing principle. These include various weighting and evaluation schemes (the US Fish and Wildlife Service's Habitat Evaluation Program is an example), and various applications of operations research methods to, e.g., optimize land use (e.g., the USDA Forest Service's FORPLAN). These and related devices make me uneasy for two reasons (but others may be quite comfortable with them for the same reasons). First, departures from the utility maximization framework leave me wondering just what instead is being maximized and why it is more appropriate than utility. Second, these devices are structured around the rational planning framework for public decisions, which is dated and moving out of favor (Randall 1985a). Perhaps a majority of economists now view the public decision process as one in which conflicting interests are adjudicated. In such a framework the BCA and SMS approaches (and alternative information systems suggested by other disciplines and combinations thereof) serve not as devices to help the planners decide but as systems presenting information that is diffused, critiqued, evaluated and ultimately used by the various interest groups and the conflict resolution institutions.[8]

Are Economic Approaches
Compatible with those of
Other Disciplines?

There is some tension between economists and practitioners of other disciplines, about the completeness and validity of various approaches to the valuation of biological diversity. At the risk of oversimplifying, let

me characterize the opposing viewpoints as follows. Some non-economists tend to argue that economics should be confined to a narrow sub-set of value categories, mostly commercial, leaving many other kinds of values in the "non-economic" domain. The economic approach•(as practiced by this author) is that all homocentric, instrumental, and utilitarian values are, in principle, within the domain of economic analysis. There are two caveats. First, the empirical information required to move from "in principle" to "in practice" is often scarce. Second, the homocentric, instrumental and utilitarian value concepts upon which BC-oriented economists rely are themselves subject to broad-ranging critiques (as outlined in Section 2, above). In this respect, I would respond to a non-economist's complaint that the economic approach is incomplete in concept as follows: No, it is remarkably complete and certainly much more complete than you think, but it operates from a particular perspective and others may legitimately critique that perspective and propose alternatives. Philosophers, for example, amy consider (in addition to the homocentric, instrumental and utilitarian perspective) arguments that: non-human organisms and associations "have a good of their own"; non-human organisms and associations have rights that impose corollary duties on humans; humans have ethical obligations toward non-human species; etc.

Philosophy and economics are thought systems that have devoted much attention to questions and concepts of value. Formal study of value concepts plays a smaller role in biological thought. An economist is likely to look to biology for technical information (e.g., about the kinds of relationships conceptualized in equations 1 and 2). Some biologists, on the other hand, are frustrated when confined to the role of technical informant, and seek to express themselves on value questions concerning

species and ecosystems. At the risk of oversimplifying, again, there is a tendency for biologists to attempt to confine economists to the "commercial values" category, and a tendency for economists to believe biologists have no disciplinary authority to discuss values at all. The potential for conflict is obvious.

5. Biological Diversity and Public Decisions: What Economics Has to Offer

Here, I summarize the argument of the previous four sections in a series of brief statements.

1. The economic approach is utilitarian, instrumentalist and homocentric. Concerns beyond that framework may be considered, on their own merits, as additional to the economic concerns.

2 The values that the economic approach recognizes cut across all of the categories (from "economic/utilitarian" to intrinsic) listed in the Statement of Work.

3. According to the economic approach, individual preferences carry considerable normative weight. Individual choices, being influenced by preferences but also by information, endowments, and the existence and completeness of markets, have somewhat less normative import. The transition from individual to societal choice presents major, and perhaps insoluble, normative problems.

4. Economics, which focuses upon, but also beyond, commercial and market behaviors, is not inherently hostile to preservation objectives.

5. Economics, as an empirical discipline, lives toward the top of the information food-chain. While it is capable of generating elegant (if perhaps not universally unobjectionable) frameworks for setting priorities, empirical implementation requires enormous amounts of information about the

physical and biological consequences of decisions, much of it currently unavailable.

6. The benefit cost criterion is directly derived from a theory of government. It implements the potential Pareto-improvement criterion which is itself one specific utilitarian answer to the question of legitimacy in government.

7. The benefit cost criterion, viewed as strict decision rule, would be unacceptable to philosophical individualists and adherents of public interest theories of government. Individualists object to its lack of concern about nonconsensual and uncompensated losses to some individuals in pursuit of even larger aggregate gains for others. Public interest theorists object to its value system, which (i) aggregates individual valuations and thus implicitly accepts the existing distribution of endowments and (ii) implicitly denies any formulation of the public interest beyond the algebraic summation of private interests.

8. Benefit costs analysis (BCA) may nevertheless serve a useful purpose in providing information for the public decision process.

9. BCA includes all sources of preservation benefits and costs which are consistent with the perspective of preservation as a resource allocation problem. Included among benefits are raw materials and amenity uses (present and future), option and quasi-option values, and existence values.

10. BCA is not inherently hostile to preservation objectives.

11. Applications of BCA are impeded by inadequacies in information about physical and biological consequences and individual and aggregate valuations of beneficial and adverse consequences. These impediments are especially severe in the application of BCA to preservation issues.

12. A survey of the literature reveals two kinds of economic information systems about preservation: an approach based on BCA with the benefit of the doubt (in a severely restricted information environment) accorded to the preservation alternative; and the SMS approach, which starts with a presumption that preservation is beneficial in every case and focuses on the opportunity costs of preservation.

13. If executive agencies were formally to use BCA or the SMS approach in decision making, the decision process would be well served by procedures that routinely open these information systems to public and professional scrutiny.

6. Biological Diversity and Public Policy[9]

The concept of biotic resources implies scarcity which, in turn, suggests the need to establish priorities in a context where every option has its opportunity costs. Three broad goals, with respect to biological diversity can be recognized: the preservation of species, and biotic associations; preservation of the scope for life processes (speciation, natural selection, evolution, etc.); and sustainable use. There is some conflict among these goals; First, preservation of what currently exists, (i.e., the life-forms and asssociations that are familiar) may involve human intervention against life processes, as the "natural course of events" tends to eliminate some species and associations while adding some new ones. Second, the goal of species preservation may be served by a strategy of preservation in zoos, laboratories, etc., while goals of preserving associations and life precesses seem most likely to be better served by a strategy of habitat preservation.

Further, scarcity guarantees that preservation goals will be in

conflict with other human purposes. "Total" or "maximum" preservation is impossible (and probable meaningless). While this implies that there is in principle some optimal "amount" of preservation, there are a multiplicity of reasons (philosophical through biological) why this optimal amount cannot be identified. Current knowledge, I would argue, is better adapted to suggesting some priorities within a broad preservation goal than to specifying the proper commitment of resources to preservation in general.

Preservation is an issue at the societal level. Economics conceptualizes individualistic, public interest, and utilitarian/benefit cost approaches to collective choice.

There is some scope for individualistic solutions to the preservation issue. Preservation of species, wild relatives of domesticated cultivars, etc., in zoos and laboratories is feasible given the opportunity for commercial activity in plant breeding, pharmaceuticals, genetic engineering, etc. There already is a substantial private sector contribution in these and related areas and this contribution can be expected to grow. Nevertheless, this contribution is limited in that it is species oriented and biased toward those species that recommend themselves as having good commercial prospects.

One would also expect, with growing awareness of the complexity and diversity of nature, some eventual commercial recognition of opportunities to profit from ecosystem preservation. Entrepreneurs could perhaps establish preserves, the main attraction being nature itself, and admit visitors, photographers, film crews, scientific expeditions, etc. Problems would inevitably arise in mediating the conflicts between human use and intervention and the integrity of the ecosystem, but these problems would differ little (in principle) from those faced by national park managers.

There is also scope for actions by volunteer interest groups,[10] ranging widely from lobbying and public relations through purchase and management of key sections of habitat.

Nevertheless, there are limits to individualistic and voluntary cooperative action for preservation. Public agencies need to be involved. Here, economics suggests the "modified BCA" and SMS approaches to setting preservation priorities and (less definitively) determining total preservation budgets.

In a rational planning approach, modified BCA and/or SMS are tools for the planners, to encourage and assist scientific decision-making. In a diffuse, interest group model of the public decision process, these are information systems helpful in agency planning but also in informing the various publics that become involved in the ultimate decision. I subscribe to this latter view.

In this context, BCA and the documentation of benefits (as well as costs) it provides can serve a major educational function: to demonstrate that the commercial interest do not always have the best of the economic arguments (Fisher 1982). For this reason, I would encourage application of BCA to preservation of biotic diversity issues, with sustained effort to document nonmarket benefits. While it is likely that much of the BCA work would be performed or funded by agencies of governments, the whole BCA process should be open to professional and public scrutiny. The purpose is to inform, to iterate toward some agreement about the scope and size of benefits and costs, to improve the information base through criticism, and to educate. Public agencies and private foundations should fund major, highly visible, case studies.

However, I would be opposed to any legislated requirement that BCA be used in every preservation decision or that a BC test be used as (literally) a filter for preservation cases. The state-of-the-art does not justify such formalism. Using a BC filter implies a rational planning procedure, which tends to limit the public scrutiny of the BCA process and its documentation, thus increasing the opportunities to distort the analysis to obtain an a priori preferred outcome.

The SMS logic, however, should be applied to every preservation issue, and its results made public. Decisions should be made with full cognizance of the opportunity costs of maintaining the safe minimum standard. Clearly, this calls for enhanced funding of research on the technology of maintaining biological diversity and the opportunity costs of so doing.

Finally, we must consider the global scene. The predominance of the earth's species live in the tropics, most of them as yet uncataloged. There is fragmentary evidence that huge areas of terrain must be left undisturbed, if the integrity of many tropical ecosystems is to be ensured. Given the poverty and population of many tropical nations, preservation of biological diversity seems to be in direct conflict with their legitimate and urgent economic development objectives.

Several observations are appropriate. First, since it seems certain that the viability of human society is linked to some minimal level of ecosystem integrity, research and education efforts to establish these relationships and communicate them to the leadership in the various tropical nations should be enhanced.

Second the opportunity costs of preservation are not always large (Bishop 1980), and commercial development of many tropical areas is not

always beneficial, or even viable, in the long term. The well-off nations could increase their support of research to better determine the various benefits and opportunity costs and to establish the limits within which economic progress and biological diversity can be pursued in harmony.

Third, where relatively rich and highly developed countries see a more pressing self-interest in preservation of tropical ecosystems than do tropical societies themselves, it is in the self-interest of the former to subsidize tropical preservation efforts thus compensating the host countries for economic development benefits foregone.

Footnotes

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1. More precisely, what the individual wants ex ante is good ex ante for the individual. Economics does not assume clairvoyance and perfect information, and there is always the possibility that something preferred ex ante will, once obtained and used, "leave a bad taste in one's mouth".

2. As the discussion has already made clear, the Economic/Utilitarian category (Statement of Work) is defined much too narrowly, to include only a subset of the commercial values. Economic and utilitarian concepts of value are not confined to commercial values.

3. For further elaboration, see Randall and Stoll (1983)

4. Note that I explicitly claim that at least some aspects of every kind of value identified in the Statement of Work can be subsumed under the economic (i.e., instrumental, utilitarian and homocentric) concept of value.

5. This is true even in the case of water resources development, where the benefit cost criterion serves as a filter for proposed projects (Peterson and Randall, 1984, p. 69).

6. Ecologists have made some progress in researching and modeling ecosystem relationships. For example, modeling for forage needs, carrying capacity and competition of wildlife/cattle has been approached by Cole (1958), Dice (1945), Hurlbert (1969), Irwin (1975), Krebs (1972), Poole (1974) and Telfer (1972) among others. Predator/prey relationships have

been modeled extensively. Important contributions include Smith and Slatkin (1973), Rosenzweig (1973), Tanner (1975) and Mech and Kams (1977). Van Ballenburghe et. al (1975), considered the issue of stability in a predator/prey relationship.

Modeling of ecosystem relationships is not so well advanced where commercial and/or game species are not involved.

7. "Incentive-compatible mechanisms" are (in principle) value-revealing for nonrival goods, but introduce a special and demanding form of exclusion: exclusion of those who do not pay their own WTP. Ordinary exclusion requires only exclusion of those who do not pay the going price.

8. See Randall (in press) for an elaboration of these cryptic comments.

9. In this section I offer some comments addressed to items 4 and 5 in the Statement of Work. Given the page limitation and the author's expertize as an economist (rather than an expert in the relevant legislation and agency procedures), these comments will necessarily be suggestive rather than definitive.

10. Recent literature on the theory of repeated cooperative games (Axelrod 1984) has shown the viability of voluntary cooperation under certain conditions. Economists are becoming less skeptical about the possibilities for voluntary cooperation.

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Contract Paper No. 2

Values and Biological Diversity

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Values and Biological Diversity

by

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Abstract

Preservation of biological diversity requires protection of genetic, species, and ecological diversity. Benefits derived from biological diversity are normally classified as utilitarian or not. But this classification is flawed because the term "utilitarian" has no clearly fixed usage. Benefits are better classified as fulfilling "demand" values (values derived from the satisfaction of felt preferences), "transformative values" (values measured as objective improvements in preferences felt), and "intrinsic" values (values had by other species and ecosystems independent of human values).

Demand values are, in principle, quantifiable as expressions of actual or hypothetical market behaviors. Limits on current knowledge of ecology and of future discoveries of uses for species prohibit a fully quantified statement of demand values derived from biological diversity. Neither transformative values nor intrinsic values can be expressed adequately on the unified scale of individual preferences. Therefore, philosophers agree that assignments of value to species and to biological diversity must include qualitative as well as quantitative values.

Three criteria for assigning value to biological diversity are discussed: the benefit-cost analysis approach, the safe minimum standard approach, and the ecosystem approach. Of these, the last two are special versions of the cost-effectiveness analysis approach.

The benefit-cost approach, as defined here, requires quantifications of all benefits. This requirement is impractical for many demand values and demonstrably impossible for transformative and intrinsic values. The SMS approach recognizes that there are qualitative (moral, transformative) reasons to preserve biological diversity, even when specific and quantified values cannot be listed. Since there are many benefits derived from ecosystems (which cannot be assigned to specific species composing them), the SMS criterion should be applied to ecosystems as well as to individual species. The resulting criterion will provide more adequate protection for biological diversity than will the popular benefit-cost approach.

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Part I. Conceptual Clarifications: What Is to be Protected?

Genetic diversity--the range of adaptations stored in the genes of a species--is often contrasted with species diversity--the adaptations represented by variation across species. (Council on Environmental Quality, 1980, p.3; Ehrlich, Ehrlich, and Holdren, 1977, p. 124) Since the evolutionary trajectory of a given species will be different in the various associations in which it struggles to survive, it is also useful to distinguish species diversity from ecological diversity, represented by the product of the number of species (worldwide or in a given geographical area) and the types of associations in which these species exist.

Biologists therefore use three concepts of ecological diversity. (Norton, under review: Whittaker, 1960; MacArthur, 1965) Insofar as an ecosystem can be understood as a system with (partially) closed spatial boundaries, one can measure within-habitat diversity. (MacArthur, 1965, p.22: Norton, under review, Chapter II) Simple counts of species existing in a system can serve as an approximate measure of this concept, but many ecologists prefer more sophisticated measures.[1] Geographical areas that contain a number of ecosystems with a variety of organizations and associations, have a high degree of cross-habitat diversity. Measures of this type of diversity reflect the heterogeneity of the habitats existing in an area. (MacArthur, 1965, p. 522; Norton, under review, Chapter II)

Total diversity is described for a geographical area and refers to the cumulative number of species in all of the habitats existing there. (Norton, under review, Chapter II; Whittaker, 1972, p. 232) Total diversity combines the idea of within-habitat diversity (the variety of species in a delimited system) and cross-habitat diversity (the variety of habitats in a geographical area), and represents the aggregate of species existing in a geographical area.[2]

When biologists and ecologists discuss and measure diversity, as when they relate diversity to stability and other ecological concepts, they usually refer to within-habitat diversity. (MacArthur, 1955) But environmentalists concerned with

preserving species are best interpreted as showing concern for total diversity. That is, concern about extinctions, whether local or global, is normally concern about the loss of a species from the corresponding geographical area. (Norton, under review, Chapter II; Leopold, 1953; Elton, 1958; Lieberman, 1975; Humke, et. al., 1975)

Part II. Two Taxonomies of Value

A. The Standard Taxonomy

What are the values served by biological diversity? Most answers to this question distinguish A. utilitarian from B. nonutilitarian reasons for preservation, grouping benefits that serve human "happiness" (often measured in economic, dollar figures) in opposition to those that serve other values.[3]

According to this dichotomy, nonhuman species and relatively natural ecosystems have unquestioned utilitarian value, providing human benefits for: (A1) agriculture, silviculture, and mariculture; (A2) industry (including pharmaceuticals, building products, etc. (A3) ecosystem services (such as oxygen production, moderation of hydrological cycles, and tertiary treatment of human wastes); (A4) knowledge (as a source of deeper understanding of the world and as a base for technological advances); (A5) recreation and aesthetic amenities (including sport taking of specimens, aesthetic viewing, photographic subjects, etc; and (A6) enrichment of human experiences, through symbolic representations evoked by wild species. (Faulkner, 1961)

Opposed to these utilitarian benefits are nonutilitarian ones, sometimes called "existence values"--values that are defined independently of human uses. These include: (B1) human non-use values, as in "it just makes me feel better to know there are bears in the area, even though I'd just as soon never run into one;„ (Randall, 1986) (B2) attributions of rights or legitimate interests to nonhuman specimens or species (Singer, 1977; Ehrenfeld, 1981, p. 208; Ehrlich and Ehrlich, 1981, p. 52; Goodpaster, 1978; Taylor, 1981) (these attributions would imply human obligations not to kill specimens or eradicate species, even if doing so harms no human being); and (B3) religious values (some religious thinkers argue that we owe to God an obligation

not to destroy other living creatures). (Schweitzer, 1976; Berry, 1979) Because difficult theoretical problems exist with (B2) and (B3), (Callicott, 1980; Norton, 1982a; Goodpaster, 1979; Callicott, 1986) some philosophers defend a related, but more general claim that some or all nonhuman species have "intrinsic" or "inherent" value.[4]

The utilitarian values in category A, which can often be measured and quantified in economic terms, are hardly questioned. Values in category B are more controversial, both because they are entirely denied by some writers (Murdy, 1975) and because they appear to be unquantifiable.[5]

The taxonomy of values here outlined is widely accepted and sometimes useful. (Ehrlich and Ehrlich, 1981, Chapter 3; Ehrenfeld, 1981; Gunn, 1984, p. 306; Myers, 1983, p. ix) Unfortunately, the central concept on which it is based, "utilitarian," is used ambiguously in the philosophical literature. Originally, "utilitarianism" referred to an ethical theory which identifies a good act as one that leads to the greatest happiness for the greatest number of individuals, and couples this identification with a hedonistic conception of happiness. That is, happiness is measured in experiences of pleasure and unhappiness in experiences of pain. (Bentham, 1961) Subsequent controversies have split and broadened this core idea. Utilitarianism currently refers to a cluster of ideas and theories united by little more than a belief that courses of action should be evaluated according to their consequences for individuals. This generic concept draws no useful distinctions when the focus is on obligations transcending species boundaries, because of at least three crucial ambiguities: (1) Whose happiness? Even its early defenders could not decide whether to count only <u>human</u> pleasure and pain, or whether to include consequences for all sentient animals.[6] (2) What counts as happiness? Are all pleasures to be counted equally Or, are intellectual pleasures "higher" than sensual ones? (Mill, 1910, p. 7f) (3) How is happiness to be determined? Can happiness be equated with the fulfillment of preferences, even though the attainment of individual misguided desires often results in misery? Or, is there to be an objective determination of happiness, which would seem to require a consensus as to the "good life?"

Often, it is assumed that happiness is to be equated with economic well-being, but this assumption is, of course, highly controversial. While this approach is useful in some contexts, it can also lead to serious confusions, because it leads to an equation of "utilitarian" with "quantifiable". But quantifiability is a controversial matter which often admits of degrees. Some economists adopt a heuristic assumption that all values can be economically quantified, even the non-use values listed in category B. Since markets do not exist for all preferred items, hypothetical market values are assigned (the price a person would be willing to pay to retain an item, WTP, or the amount a person would accept to give up the item, WTA). (Randall, 1986) Advocates of economic quantifiability would admit that figures assigned by the methods of WTP and WTA to the protection of rights, religious values, and intrinsic values are approximations, but they would insist that they are useful approximations. Many advocates of non-use values insist, however, that they are neither economically quantifiable, nor commensurate with quantifiable values. (Ehrenfeld, 1981, Chapter 5; Regan, 1981, p. 32) References to utilitarianism, therefore infuse all of the confusing issues of quantifiability into the taxonomy of values.

Thus, while the generic concept of utilitarianism is useful in drawing a distinction between consequentialist theories of value and other theories emphasizing rights and duties (often described as "deontological"), it raises more questions than it answers as a classification of values derived from biological diversity. The questions listed two paragraphs back must be answered in order to give any useful meaning to the concept of utilitarianism when applied to cross-species value judgments; the capacity to experience and register the types of pleasure and/or happiness mentioned are variously distributed among species. To assume any particular answers to these questions exceeds any consensus among ethical theorists, however, and would beg important questions of value in cross-species evaluations. Taxonomies of interspecific value based on the dichotomy between utilitarian and nonutilitarian values, therefore, provide at best imprecise and shifting categories.

Finally, as it is usually employed, the dichotomy between utilitarian and nonutilitarian values promotes thinking according to a false dichotomy. Many writers argue as follows: The use of nature to fulfill human needs results in alteration and conversion of more and more ecosystems for human use. Human needs and desires expand indefinitely as population and material aspirations increase. Therefore, natural ecosystems can only be preserved if humans recognize that nonhuman species have rights (or, intrinsic value, or religious value, etc.) that limit the fulfillment of human needs and desires. (Ehrenfeld, 1981; Routley, 1973) This argument encourages a false dichotomy because it assumes that the expansion of human needs and desires is a given. If humans have practical or ethical obligations to other humans to limit their population and/or needs and desires, it could be responded to this argument that there are reasons, independent of nonhuman rights and intrinsic values, that justify a policy of reducing the rate of alteration and conversion of ecosystems. This is a point that will be given further explanation, below. Here, it is important because it shows that the most popular taxonomy of values derived from biological diversity is not only unclear, it can also close off important avenues of exploration in the search for a complete cataloguing of values supporting biological diversity.

B. An Alternative Taxonomy

The popular taxonomy based on a dichotomy between utilitarian and nonutilitarian values is deeply engrained, and it is unlikely to disappear from common parlance. Nor is such a disappearance necessarily desirable, as the taxonomy is useful in some imprecise contexts. Nevertheless, the actual and potential confusions it promotes make a more precise alternative desirable.

To obtain a more precise categorization of values, it is necessary to define: (a) a "felt-preference" as any desire or need of a person that can be sated, at least temporarily, by some specifiable experience of that person, and (b) a "considered felt preference" as any desire or need that a person would express or otherwise exhibit after careful deliberation. (Norton, 1984, p. 134) Careful deliberation is

then defined as including a judgment that the desire or need would still be expressed by an individual in full possession of a "rational world view."

This idealized concept would in turn include a fully verified scientific theory of all aspects of the world, an adequate metaphysical understanding of these theories, and a set of rationally supported aesthetic and moral ideals. While it is doubtful that any person ever will fully develop such a world view as this, the concept of a considered preference provides a normative criterion for judging felt preferences--preferences not consistent with current scientific information or rationally defensible value commitment cannot be described as considered preferences.

Felt preferences are often taken as givens, so that they can be aggregated to determine a group preference, and to justify a policy as most likely to fill the broadest range of felt preferences. But felt preferences can also be criticized. Considered preferences are then relevant; a felt preference would be a considered felt preference if it would survive examination in light of very stringent criteria of rationality. And, while fully considered preferences represent a normally unattained ideal, they function regulatively: if a felt preference is inconsistent with a known scientific fact or with well supported aesthetic or moral ideals, it can be judged not a considered preference. While this judgment will always be made from some point of view, unrefuted criticisms justify placing less weight on unconsidered preferences. When felt preferences are being criticized, rather than accepted, such judgments can result in less weight being placed on such preferences. Suppose, for example, a person expresses a desire to fly without the aid of technology. Such a felt preference could be discouraged, and the person persuaded to back off from a mountainous cliff, by reference to well accepted laws of nature and a reference to the ideal of longevity of human life. Preferences can, therefore, be judged unconsidered, even when the development of a fully supported world view remains incomplete.

Armed with these concepts, it is possible to define (c) <u>demand values</u> as the value invested in an object for its role in satisfying some felt preference, whether it has been considered or not. Thus, an object, such as a specimen of some nonhuman

species or the species itself, has current demand value in proportion to its current potential to satisfy a felt preference.

Opposed to demand value, an object has (d) transformative value, if it provides occasions for the examination or alteration of a felt preference. For example, a person might intensely desire a fur coat made from the pelts of bobcats. Bobcats therefore have demand value corresponding to the intensity of that desire, and the amount that person is willing to pay for such a coat would stand as a measure of this value. Suppose, however, that the person in question encounters a bobcat in its wild habitat, while walking in a wildlife refuge, and begins to study the species. It is learned that the species' existence in the area is threatened by trapping, and that the animals suffer greatly when trapped. If the person renounces the desire to have a coat as a result of the chance encounter and reflection upon it, the bobcat in its natural habitat has exhibited transformative value: it has precipitated a consideration of a felt preference and led to the conclusion that the desire for a fur coat is not a considered value for that person. It is also, of course, possible that the person will persist in desiring the coat after such a re-examination. To call a demand value unconsidered is not to make a prediction about actual behavior. It is, rather, to argue that a fully rational person would abandon the demand.

It is also useful to distinguish (e) anthropocentric values from (f) nonanthropocentric values. (Norton, 1984, pp. 133-5) Anthropocentric values are values which serve human interests, while nonanthropocentric values are located in nonhuman species or objects. An anthropocentrist, therefore, argues that all value, whether demand or transformative, derives from human beings. All value is instrumental to fulfilling human goals and motives; no nonhuman object has "intrinsic value," value that exists independent of human value. Nonanthropocentrists, on the other hand, believe that some nonhuman individuals, objects, or species have intrinsic value. This value does not depend on its contribution to human welfare, no matter how broadly construed. Note that the distinction between anthropocentric and nonanthropocentric values is not equivalent to the economists' distinction between utilitarian and nonutilitarian

values for two reasons. First, anthropocentric values include transformative values, which cannot (I will argue below) be expressed in terms of a utilitarian scale of preference satisfaction. Second, nonanthropocentric values may or may not be expressible in utilitarian terms, depending on whether nonhuman preferences count. (Singer, 1977).

These distinctions yield the diagram shown as Figure 1 (page 8). The four boxes designated by the intersection of the rows and columns represent alternative approaches to rationales for preserving biological diversity. I.i represents those theorists who believe that biological diversity has value in fulfilling human demand values, and that all values can be interpreted as human preferences (demands). Included here are values (A1)-(A6), above, insofar as these values are seen as fulfilling human felt preferences.

Figure 1

	I of humans only (only human interests are counted)	II of humans and nonhumans (nonhuman as well as human interests are counted)
I.i values	II.1 strong anthropocentrism	i. demand nonanthropocentric
ii. transformative values	I.ii weak anthropocentrism	II.ii nature mysticism

Box I.ii includes theorists who recognize, in addition to those recognized in I.i, values deriving from the transformation of human preferences. That is, in addition to demand values fulfilled by (A1)-(A6), they emphasize that (A4)-(A6) have transformative value as well. Thus, according to these theorists, knowledge of other species, aesthetic interactions with other species, and symbolic experiences encouraged by other species can play a role in reconsideration and criticism of human felt preferences. When humans learn about the natural world, when they are moved aesthetically, and when they are encouraged by other species to see the world symbolically, they may be led to re-evaluate, criticize, and reconstitute their view

of the world. They may, in the process, alter their value systems, rejecting certain felt preferences in favor of values closer to considered felt preferences. Weak anthropocentrists are thereby characterized by the belief that many felt preferences are irrational--that a fully informed and consistent person would reject them. Environmental policy ought not, therefore, to be predicated on unconsidered demands.

Nonanthropocentrists (theorists in Box II.i) recognize, in addition to anthropocentric demand values and possible anthropocentric transformative values, nonanthropocentric demand values. That is, they believe that nonhuman species have intrinsic value. On this view, rational and ethical decisions must take into account not just human interests, but the interests ("demands") of nonhuman species, as well.

Theorists in the final category, represented by Box II.ii, attribute value to transformations in nonhuman demand values. (Schopenhauer, 1883; Whitehead, 1925) This approach would require attributions of consciousness to nonhuman species, and therefore requires highly questionable metaphysical views. While some theorists have proposed nature mysticism as a basis for preservationism, this approach would appear to be too speculative to guide policy at this time. (Norton, under review)

This alternative taxonomy avoids the vexing problems afflicting the popular taxonomy based on utilitarian versus nonutilitarian values. The introduced concepts are precisely definable and not susceptible to misinterpretations deriving from the vague and ambiguous use of the term, utilitarian. Most importantly, the proposed framework avoids posing the question of valuing biological diversity in a way that offers only two alternatives. The introduction of transformative values allows, in addition to valuing biological diversity only for the fulfillment of human needs and/or for the intrinsic value of nonhuman species, the recognition that nonhuman species have value as occasions to enlighten and transform human consumptive desires. It may be tempting to treat transformative values as a form of enlightened utility--but, as will be shown below, transformative values are not reducible to a single scale of values. When environmentalists criticize certain demands as irrational and not deserving of equal weight, they go beyond the utilitarian tendency

to treat all human satisfactions as having equal value, provided they are of equal intensity.

Part III. Models and Methodologies to Evaluate Biological Diversity.

The tripartite taxonomy developed in Section II suggests that a complete model for evaluating biological diversity would exhibit three main components.[7] There would be one component which measures the human demand values derived from biological diversity. This component, although defined without use of the confusing term, utilitarian, would embody the human benefits often described in that category (i.e., A1-A6, above). A second component would encompass "transformative" values, the value that is attributed to experiences which result in re-examinations and reformations of human demand values (at least A4-A6 can be seen as embodying transformative, as well as demand, values). The third component would characterize ethical and religious obligations of humans to respect nonhumans as possessors of intrinsic value.

A. Human Demand Values

When humans use some natural product to satisfy a need or desire that they have (a felt preference), they derive demand value from nature. Insofar as these satisfactions depend upon biological diversity, they represent value placed on that diversity. This value can be understood as the increment in value resulting from the use of the chosen natural product over the best available substitute. (Assuming, with the utilitarians for the moment, that happiness is related to need and desire fulfillment, this natural product represents a value corresponding to the increment in happiness deriving from the use of the product.)

Demand values can be measured in two quite different ways: subjectively or objectively. An example will illustrate. Suppose a person with a "sweet tooth" desires a snack. Available are fresh fruits and candy made from refined sugars. If the person chooses candy, this can, subjectively, indicate that it is of higher value to him/her. If, however, this choice results, in the long run, in a further craving for sweets and eventual tooth decay, one might, objectively, insist that the fresh

fruit had more value by deducting the disvalued experience of drilling and filling from the sum of satisfactions derived from eating refined sweets.

Because it is virtually impossible to know all of the effects of any course of action and because, in modern democracies, it is believed that individual freedom to choose provides a better basis for decisions than imposed decrees, most models measure "utilitarian" values subjectively. On the proposed taxonomy, demand values are treated as subjective preferences, by definition. It is therefore possible to treat individual preferences as determinative of demand value. On this subjective model, knowledge that refined sugars promote tooth decay is only relevant to the extent that it is known by the individual chooser and affects his/her choice. (Randall, 1986)

This preference satisfaction model for measuring demand values has several advantages in policy evaluation. First, it need not delay decisions in futile search for complete knowledge of the effects of proposed actions. More objective models are difficult to implement because one never has as much information as would be ideal. For example, the lover of sweets could insist, in the face of evidence that candy causes tooth decay, that it may also have as yet undiscovered positive effects on longevity or psychological health. While these claims are objectively testable, there would be an indefinite number of such hypotheses to test, delaying definitive results.

Second, preference satisfaction models can hypothesize a single scale for measuring demand values--the value of any object or experience to an individual corresponds to the intensity of the desire expressed for it. More objective models might insist that some values, though expressed no more intensely, are "higher" than others. (Mill, 1910) Completion of objective determinations based on differently weighted values would then wait upon the philosophical evaluation of such claims.

By adding to these two points an economic assumption, that individuals express their choices in markets, these intensities can be represented as the amount a person pays (in actual, or would pay in hypothetical, markets) for the satisfaction of the preference in question.

Once individual preferences are determined according to actual or hypothetical market techniques, the social value of an increment in biological diversity is obtained by aggregating the individual preferences of all (or representative) members of the society. Thus, while models which attempt to rank possible courses of action according to objective criteria may prove useful for questioning preferences and informing individuals that their choices may have unforeseen effects,[8] subjective preference satisfaction models provide the most useful means to characterize demand values in policy formation.

B. Transformative Values

Demand values can be expressed on a single, subjective scale (intensity of preferences) and in economic, quantitative terms (measures of dollars actually or hypothetically spent in markets). Transformative values represent the pursuit of a more rationally defensible system of value and scientific knowledge. Demand values, treated as subjectively expressed intensities of preferences stand as one basis for policy determination--these values register the actual wants, needs, and desires of members of the society. How are transformative values to be registered? It has been suggested that desires for preference satisfactions can serve as a determination or at least as an approximation of all human values derived from biological diversity. (Randall, 1986) Consider again the example of the person who expresses a desire to own a coat made from pelts of bobcats.[9] If this individual is willing to pay $5000 for such a coat, bobcats have demand value for this individual equivalent to the difference between $5000 and the demand value of the next less preferred alternative. In order to determine the actual preferences of humans regarding bobcats at a given point in time, this dollar figure (n) must be taken as fixed and unquestioned for that person at that time. Suppose that, subsequent to registering this demand value, the person accidently encounters a bobcat in the wild. Intrigued, he/she reads literature from an environmental organization and learns that the bobcat is in danger of extinction and that bobcats are captured and suffer greatly in leghold traps. Now our

subject is troubled and wants to learn more, and eventually rejects her previous preference for a fur coat.

The demand value, once fixed for the sake of computation and decision making now changes. If it is believed that the new set of preferences is "better" (more highly valued, more "considered"), can the value involved be registered on the scale of demand values? To some extent it can. The person no doubt spent some money to prepare for, and travel to, the wildlife refuge where the bobcat was sighted. When the society's demand values are aggregated, gifts from private donors to the education fund of the environmental organization represent desires on the part of other citizens to encourage alterations in consciousness such as those exemplified by the change in our subject. (Randall, 1984) Transformative values deriving from bobcats will, therefore, be registered in the social aggregation of demand values as money spent to hike in natural, undisturbed areas and to educate members of the society to the value of wild species and wild ecosystems.

Can <u>all</u> transformative values be registered, in this and similar ways, as demand values? Can transformative values be reduced to demand values? Two arguments show that such a reduction cannot be completed.

First, so that preferences can be placed on a single scale of value and aggregated across the society, they must be temporarily fixed, frozen at a given point in time. But transformative values are values deriving from alterations, through time, of preference rankings. The value of such changes in rankings cannot be expressed within the ranking. (Norton, under review, Section XI.2)

Second, transformative values cannot be expressed as demand values within a market, because the market approach to preferences is purely <u>descriptive</u>. (Norton, under review, Section XI.2) It may be possible to register the value some individuals place on natural things by determining how much they contribute (or would be willing to contribute) to ensure their protection. This will include their contributions to "educate" or "convert" others to their point of view. In this way, transformative values of some individuals can be registered, using actual or hypothetical market

techniques, on the unitary scale of demand values. But species preservationists do not merely intend to say that some individuals are willing to pay for protection of species--they are making the stronger claim that it is wrong not to protect them. To see that these are not the same, imagine that archaeologists uncover a culture in which it was universally believed that extinguishing species is good, and that people in that society acted accordingly. In such a society, there would be no demand for species preservation. But despite this descriptive determination, environmentalists would be consistent in maintaining that the whole culture was, given what we now know, mistaken. This judgment need not be supported with evidence that there existed within the culture a secret society for protecting species--it can be based on rational arguments supporting the value of species. Many environmentalists believe such arguments exist--and that they exist independent of individual demands as these are expressed in markets, actual or hypotheical. The soundness of these arguments depends in no way upon the actual or hypothetical behaviors of individuals in markets.

Transformative values, therefore, cannot be expressed on the unitary dollar scale of human demands. Nor can they be expressed as intensities measured by market techniques. They justify changes in the actual preferences expressed on the scale of preferences.

C. Nonanthropocentric (intrinsic) Values of Biological Diversity

The most controversial category of values cited for preserving biological diversity are intrinsic values attributed to nonhuman species, individuals, and natural ecosystems. Intrinsic value was defined above as value not deriving from contributions to the values of other beings.[10] Most value systems espoused in philosophy historically are anthropocentric, recognizing only humans as having intrinsic value. On these systems, other living things and nonliving objects are treated as having only instrumental value.

Recently, it has been argued that anthropocentric assumptions must be rejected; according to these arguments, an environmental ethic sufficient to protect the natural world from destruction must be based upon recognition of intrinsic value in nature.

(Routley, 1973; Regan, 1981) Nonanthropocentric theories can be placed in three categories: (1) theories attributing individual rights and individual interests to nonhuman specimens, on analogy to individual human rights; (Singer, 1977; 1979; Goodpaster, 1978) (2) theories that attribute intrinsic value to nonhuman individuals, species and ecosystems, (Taylor, 1981) (3) theories that attribute intrinsic value to other species and ecosystems, but not to individuals. (Callicott, 1980) In general, theories in categories (2) and (3) place progressively less emphasis on individuals and more on species survivability and ecosystem integrity.

No consensus has emerged in the adolescent field of environmental ethics as to (a) which objects have intrinsic value, (Callicott, 1980; Taylor, 1981) (b) whether any nonhuman objects have intrinsic value, (Murdy, 1975) (c) whether attributions of intrinsic value are essential to support an adequate environmental ethic, (Regan, 1981; Norton, 1984) or (d) whether an environmental ethic is enhanced by appeals to intrinsic values. (Sagoff, 1974; Murdy, 1975) A complete catalogue and evaluation of arguments on these various issues would require more space than is available here. The reader is referred to more detailed sources. (Attfield, 1983; Taylor, 1981; Norton, under review; Gunn, 1984; Regan, 1981)

Under the circumstances, it is difficult to assess what role intrinsic values should play in policy formation. A compromise position can be suggested: believers in intrinsic value would argue that, if nonhumans have such value, current human preferences will have to be altered. Intrinsic values in nature, if they exist, would function as ethical ideals regulating and reforming those preferences. Since there is widespread agreement among environmental ethicists that the current set of human preferences (whether for large families or for wasteful, consumptive lifestyles) are environmentally destructive, consensus can be reached on the claim that a transformation of current human preferences is desirable. (Sagoff, 1974; Murdy, 1975; Singer, 1979) This consensus is independent of any disagreement over whether nonhuman intrinsic value exists or must be recognized in order to justify such transformations. That is, there seems to be agreement on the conclusion that value transformation is

needed, but little agreement on whether such a transformation will incorporate radical expansions in the class of beings attributed intrinsic value. Policy initiatives should therefore be based on the need to recognize and take into account transformative values, in addition to demand values. The question of the exact meaning and role of attributions of intrinsic value to nonhuman species and ecosystems can then remain a question for future discussion in philosophy; it need not be settled in order to draw important conclusions concerning the values protected in policy formation.

The proposed consensus converges on the following implication: qualitative, as well as quantitative, values must be countenanced in public decisions regarding biological diversity. Demand values, which can be quantified using actual and hypothetical market indicators, are quantifiable because they reflect the unified, descriptive scale of preference intensities. Defenders of intrinsic value of nonhumans insist that these values cannot be quantified or placed on the same scale as human interests (demand values).[11] It was shown in Section IIIB that transformative values cannot fully be represented on the scale of demand values. Environmental philosophers therefore agree that the full range of values deriving from biological diversity cannot be quantified on a single scale of human preferences. Qualitative values that qualify, reform, and transform those preferences must guide public decisions affecting biological diversity.

D. Economic Models for Decisions Affecting Biological Diversity

To summarize, it will be useful to apply the conclusions of Sections IIIA-IIIC to the use of economic models. Because linguistic usage is not uniform, the following terminology will be stipulated. A benefit-cost analysis model (BCA) refers to a system of public decisions in which (a) all values affecting a decision must be quantified monetary representations of intensities of human preferences and (b) public decisions should be directly determined by rankings of possible courses of action, with the course chosen being the one which is predicted to yield the greatest surplus of preference satisfactions represented as dollar figures over computable monetarily represented costs.[12] Economic analyses need not be limited to CBA's as here defined.

One alternative economic model, known as the SMS (safe minimum standard) criterion, is especially important. (Ciriacy-Wantrup, 1968; Bishop, 1978) This criterion begins with the assumption that resource protection is always preferable because it maintains future options. This criterion councils: Avoid extinction unless the social costs of doing so are unacceptably large." (Bishop, 1978) This criterion incorporates concern about irreversibilities, does not require a quantified specification of benefits, and places a burden of proof on options that predictably decrease biological diversity.

The arguments of Sections II.A and II.B show that rational decisions concerning the goals to pursue in protecting biological diversity must countenance transformative values, values that cannot be reduced to quantifiable intensities of individual preferences expressed in markets. The CBA model as here defined, therefore, does not represent a complete approach to determining the value of biological diversity.

Because philosophers tend to discuss broad conceptual and value issues, they have not produced anything approaching a model for valuing biological diversity. It is possible, however, to state certain generalizations which accepted philosophical arguments place on any adequate models for this purpose.

First, philosophers distinguish intrinsic from instrumental value. The intrinsic value of an object is the value it has independent of its value to some other conscious agent, while instrumental value is the usefulness of the object in fulfilling the needs or goals of another agent. Philosophers agree that humans derive important instrumental values from biological diversity (see above, A1-A6). Many philosophers would grant that these values are, in principle, represented as quantified intensities of individual preferences. It is often pointed out, however, that practical problems in assigning numerical values requires caution, even here.

A significant number of philosophers argue that, in addition to instrumental values, wild species and functioning ecosystems have intrinsic value. As was pointed out above, at III C, attributions of this sort of values to nonhuman living things is highly controversial. Some theoreticians attribute value completely independent of

humans to nonhuman living things (Taylor, 1981). Others would say that nature has value because of the love and respect we hold for it. (See the first referee's report on my draft--I believe this report was written by Mark Sagoff.)

I have advocated the view that nature has, in addition to instrumental, intrinsic, and "love and respect" values, "transformative" value. This concept assumes that environmentalists judge many of day-to-day preferences to be misguided--such as the preference for a fur coat from the pelts of an endangered species. If encounters with wild species and natural ecosystems cause reconsideration of these misguided preferences, leading to more rationally defensible preferences, then the experience of nature has transformative value. If someone fails to have such experiences, or reconsiders and still desires the fur coat, then this type of value is not consummated. Judgments of transformative value are always dependent upon a prior judgment that some preference is more rational than another. Advertisers present experiences that they hope will transform preferences. Such transformations can be positively valued (If one believes the new preference is more rational), negatively valued (if one believes the new preference is less rational than the one it replaces), or neutral (if the new and old preferences are equally rational). The transformative value of nature therefore, depends upon an assumption that many current preferences of our society are irrational, and that environmentally sensitive preferences would be more rational. If experience of wild species and unspoiled ecosystems facilitate the replacement of irrational, environmentally insensitive preferences with more rational, environmentally sensitive ones, then they have transformative value.

Philosophers, therefore, have posited four general types of values of biological diversity-- (a) the value of species and ecosystems in fulfilling human demands; (b) the independent intrinsic value of species; (c) the attributed intrinsic value deriving from the love and respect for wild things because of what the thing is; and (d) the transformative value of wild species.[note: (b) and (c) were not distinguished in my original discussion of intrinsic value.]

Philosophers would agree with economists that it is important to know the commercial and economic value of biological diversity i.e. (a). They would, also, agree that actual and hypothetical market analyses provide a useful approximation of these values, although they often argue that individually expressed preferences are inadequate as a representation of long-term future values, of values that require knowledge of ecosystem functioning, etc.

Philosophers who advocate (b) claim that such values are not commensurate with instrumental, economic values (Regan, 1981). They will, therefore, insist that economic analyses provide only a partial approach to decision making. Unfortunately, little agreement exists, even among believers in (b), about how these value should be balanced against economic values.

Values of type (c) ("love and respect") could be factored into an economic analysis, if one believes that willingness-to-pay for protection of a species, for example, is a reasonable measure of love and respect for it.

Transformative values, type (d), however, cannot be factored directly into economic analyses, because these analyses tend to take preferences as "sovereign" (see note #17). Transformative values represent the value of shifts in preferences.

What, then, can be said by philosophers about models for valuing biological diversity? Most philosophers would advocate economic models as a means to approximate the effects of protection on the fulfillment of human preferences, although they would emphasize the incompleteness and inadequacy of current techniques as a complete accounting.

Most philosophers would argue (based on (b) or (d), above) that economic analyses are, in principle, inadequate to give a full accounting of the values of biological diversity. But even aside from adequacy of (b) and (d), they would argue that economic values must compete with other social values, and that the determination of the proper goals of a policy to preserve biological diversity must result from a political process. Consideration of economic efficiency would carry considerable weight in such a process, but these must be balanced against other values--risk aversion, concern to

protect independent intrinsic values, in nature, love and respect for living things, and the desire to live in a decent and rational society, concern for distributive justice, and so forth. I conclude that most philosophers would be most likely to advocate the SMS approach to species preservation.

Once political goals for preserving biological diversity are hammered out legislatively, economic analyses will then be most valuable in rating the effectiveness of various means to achieve these goals. (Sagoff, 1984)

Part IV. Problems in Recognizing the Full Value of Biological Diversity

The values derived from biological diversity are pervasive; they affect every member of the society every day. But they are seldom paid for directly since they are often readily available for the taking. And, when they are paid for, they usually have been modified or packaged and appear as products of human artifice. Because the benefits of biological diversity are often readily available and free of cost, it is easy to take them for granted. The purpose of this Part is to list specific problems involved in fully recognizing the value of biological diversity.

A. Problems in Fully Recognizing the Demand Values Fulfilled by Biological Diversity

Demand values are, in principle, measurable and quantifiable--given complete knowledge of what members of the society need and desire at a given point in time. Given knowledge of the intensity of them, knowledge of the ways in which products of a biologically diverse biosphere can fulfill those needs and desires, it is in principle possible to compute the total dollar value of biological products for the fulfillment of human preferences. But our knowledge falls far short of these ideals in every respect and such a computation far exceeds present abilities. Even if such a computation were completed, however, it would be a computation of what people want at this time. And, while it is true that individuals want assurances in the present that products will be available to fulfill future demands, it is clear that a systematic bias affects the comparative intensity of preferences for present over future gratifications. The nature of this bias is not well understood, and great care is necessary in characterizing it or the result will understate the demand values that

might be fulfilled by units of biological diversity which could be destroyed by over-zealous pursuit of present satisfactions.

1. Contributory Values Fulfilled by Biological Diversity

Most attempts at assigning values to biological diversity begin with a species-by-species approach. (Council on Environmental Quality, 1980, p. 36; Norton, under review, Chapter II) A particular species is singled out and described in terms of its populational characteristics and the characteristics of its individual members. Values are then assigned to the species based on these characteristics and their efficacy in fulfilling human needs. Given this approach, the value of biological diversity can only be computed by aggregating the values assigned individual species.

This approach will never be successful in even approximating an account of the true value of biological diversity. First, no actual computation of "the value of a species" is ever completed, because it is impossible to know what values will be discovered in the future, and because species may well have subtle values not recognized at the time of evaluation. (Norton, under review, Section II.3)

Second, the species-by-species approach fails to recognize the contributory value of species. (Norton, under review, Section III.4) The stock of species in an area is not fixed. Ecologists agree that increases in diversity in an area promote further diversity, both in ecological and evolutionary time. (Whittaker, 1969, p. 188; Whittaker, 1972, pp. 241f; Harper, 1977, pp. 712-713; Whittaker, 1970, p. 103) Through the ecological processes of competition, predation, etc., niches are differentiated and new opportunities arise for more specialized species to carve out new niches. These processes create new microhabitats and lead to a patchy environment with greater cross-habitat diversity, as species adapt to the specific opportunities and threats presented by varied biotic and abiotic factors. (Levin, 1976; Norton, under review, Section III.3) The ecological processes creating diversity also function, in evolutionary time, to create genetic diversity and speciation. (Whittaker, 1970, p. 103)

Failure to distinguish within habitat, cross-habitat, and total diversity has led to confusion on the relationship between ecosystem development and diversity.

(Norton, under review, Section IV.3) It is said that ecosystems need not tend, through successional developments, toward greater diversity. This is true, as some mature systems are relatively simple. As systems develop, however, they develop structure that allows the partitioning of habitats, creating greater between-habitat diversity (patchiness) and, consequently, greater total diversity over the whole area. (MacArthur, 1965; Norton, under review, Section III.3)

The hypothesis that diversity augments diversity holds in reverse, as well. (Terborgh and Winter, 1980) Losses in diversity beget further losses, and the upward diversity spiral can be slowed and eventually reversed by concerted pressures toward simplification. Whenever a species is extirpated from an area, the other species interacting with it must adapt. Some will, eventually be lost, and these will, in turn, affect other species.[13] Even a species which has no specifiable value to humans will participate in ecological processes, and may be essential for the continued existence of other, valuable species. But ecologists know very little about dependency relations among species as it is impossible to identify, let alone compute, these contributory values that all species have. (Norton, under review, Section III.4) To evaluate decisions on a species-by-species basis leads inevitably to a disastrous pattern of incremental loss as ecological redundancy is reduced and a self-augmenting process of simplification begins. (Lovejoy, 1986; Ehrenfeld, 1981)

When these factors are taken into account, it follows that every species extirpation carries with it, in addition to losses in value directly attributable to the species in question, increased risks of ecosystem collapse.[14] The threat of such collapses creates "zero-infinity dilemmas"--decisions where there is a low probability of highly detrimental consequences. (Page, 1978;1979) Economists agree that zero-infinity dilemmas defy useful quantification in decision-making models, and can only be resolved by adopting high-risk or low-risk strategies. (Mishan and Page, 1979)

These long-term demand arguments, based on the contributory value of species, on the lack of reliable ecological information on ecological interdependencies among species, and on the inability of decision models to countenance reliable quantified

estimates of zero-infinity risks, indicate that the species-by-species approach to evaluating species is bankrupt. These arguments are even more convincing when applied to the question of evaluating biological diversity. It is impossible to generate the value of an organic, interdependent system of species by listing the specifiable values of individual species and aggregating these. The SMS approach, which states the goal of preserving species and ecosystems, provided that the costs are not excessive, at least partially avoids these problems. (Norton, under review, Chapters II and III)

2. Diffusion of Interests and Common Property Resource Problems

Individual species, and biological diversity more generally, can be viewed as "common property," susceptible to open access. That is, the benefits are available to all members of the society, and the resource (as opposed, perhaps, to individual specimens) are not subject to individual ownership. In such situations, benefits derived by individuals from exploitation of the resource are concentrated and priced as individual exploiters gain measurable value. But the costs of destruction of the resource are diffuse and unpriced; they are distributed throughout the society and are not priced in markets.

It is well established that, under such circumstances, self-motivated, rational individuals will tend to exploit the resource beyond its capacity, leading to diminution and eventual destruction of the resource. (Hardin, 1968) There are, however, two somewhat different interpretations of this tendency. Some commentators emphasize the role of lack of ownership, suggesting that resource destruction results simply from asymmetries just explained.[15] More recently, resource use models have shown that resources, even when privately owned, may be exploited destructively. If there exist alternative investment possibilities available so that profits from excessive exploitation can be re-invested in other profit-making ventures as the resource is depleted, even privately owned resources will be over-exploited. (Clark, 1974; 1976; Fife, 1971; Norton, 1982b) On this broader, time-frame interpretation, resource depletion results from a natural favoritism for present over future income

(on the assumption of diverse investment opportunities), rather than from ownership factors. These models would suggest that private ownership of natural habitats would not guarantee preservation of biological diversity, if those habitats are managed to maximize profits.

3. Irreversibility, Discounting, and Intergenerational Equity

If incentives for the destruction of biological diversity should be understood according to the time-frame model, as just suggested, then means to adjudicate between demands for short-term benefits versus demands for long-term benefits are crucial. Four types of methods have been suggested for such adjudication:

(i) Discounting. When computing the value of public investments, such as dams or highways, stated costs and benefits are normally "discounted" by a variable percentage rate (sometimes linked to the real rate of interest on money). (Fisher and Krutilla, 1975; Solow, 1974; Doelman, 1980) On this method, costs incurred and benefits accrued in the first year are computed at 100%, while costs and benefits in subsequent years are computed at a percentage of 100 minus the chosen discount rate (reiterated each year). The time-frame over which costs and benefits are considered will therefore be determined by the size of the discount rate, as the annual percentage of real costs and benefits tends toward an asymptote approaching zero. If protection of biological diversity were considered as a social investment, then a discount rate would provide one means to relate current to future interests.

Losses in biological diversity, however, are often irreversible. Since there has been limited success at re-introductions of species locally extirpated, (Campbell, 1980) most simplifications of systems approach irreversibility. Consequently, current actions that decrease biological diversity will have costs spread over the indefinite future, while benefits derived from such actions will often end at a specifiable date in the relatively near future. Consequently, economists recommend that relatively small discount rates be applied to decisions affecting biological diversity. (Fisher, 1981) But any rate greater than zero will determine that effects of diminishing biological diversity will have uncounted future costs. Strong arguments show that

decision making based on discounting result in unfair distributions of resources across time. (Williams, 1978) Thus, while discounting at a relatively small rate can take some limited account of mid-range (twenty to one hundred years) values derived from biological diversity, considerable long-term values are necessarily ignored by use of the method of discounting. This method should not, therefore, be used as the sole means to determine time preferences regarding the value of biological diversity.

(ii) Intergenerational equity (justice). Concerns that many resource use questions are asymmetrical because of irreversibilities have led some philosophers to propose that these decisions should be governed by rules of justice applied across generations. Models of distributive justice are based upon the intuitive idea of fairness among individuals. Normally, such models are time-bound in that they assume a given number of claimants to a given amount of goods and services. (Norton, 1982b) Rules of interpersonal justice then require equality of treatment for all individuals, which is taken to mean that, unless some good and relevant reason can be given to justify unequal distributions, each individual should receive an equal share. While it would require great care to specify exactly what counts as a good and relevant reason, it is assumed that such specifications can also be guided by an intuitive sense of justice. If so, some writers suggest, irreversibilities inherent in resource use questions can be conceptualized by extending concern for individual justice across generations, insisting upon a just distribution of goods to all individuals across time. (Rawls, 1971, pp. 283-297; Kavka, 1975)

While this conceptual approach succeeds in emphasizing that decisions made in the present must take irreversible effects on future resource availability into account, it resists operationalization. Decisions about fair distributions, as was pointed out, assume a given number of claimants to a given amount of goods and services. But these assumptions do not hold across time, as decisions made at present could destroy the productivity of a resource, diminishing its ability to provide goods and services in the future. Or, decisions to overpopulate now may affect the number of claimants, and might make impossible any distribution sufficient to support present and future

people. (Parfit,1983; Norton, 1982b) That is, central assumptions of the model of distributive justice do not hold across time and, therefore, the model provides no direct help in accounting for irreversibilities. Some writers have suggested modifications of this model, but these seem to introduce more problems than they solve.[15]

(iii) The Safe Minimum Standard and Sustainable Yield Models

Temporal asymmetries resulting from irreversible effects of resource use decisions have led many economists and philosophers to favor models based upon, first, a safe minimum standard as a central policy and, second, a statement of an upper bound on resource use, to be determined by some characterization of an indefinitely sustainable yield of useful products from natural systems. Extension of this approach to nonrenewable resources would require guidance based on availability of substitutes for exhausted resources.

On these approaches, no attempt is made to predict how many individual claimants will actually exist as members of future generations or to judge the legitimacy of their claims. Rather, emphasis is placed upon determining, scientifically, levels of resource exploitation consistent with indefinite regeneration of resource outputs. Several alternative conceptualizations of this general idea exist, and they share the safe minimum standard as stating the general consideration that current resource use ought not, ideally, to lessen productive possibilities of the future. The variations on this approach can only be summarized briefly here:

a. Sustainable Yield of Specific Resources--Population biologists can compute sustainable yields of populations based upon scientifically supported reproductive rates, early mortality resulting from natural causes, etc. The goal is to predict a level of exploitation which maximizes current annual takes, without diminishing reproductive rates. This approach has promise in that it enlists scientific data and theory in the difficult task of ascertaining levels of exploitation consistent with the fulfillment of future demand values. Some commentators have, however, questioned the attempt to sustain maximal annual yields, because climatic and other conditions cause annual fluctuations in the rates of survival, etc.

b. Optimal Yield of Specific Resources. It is well known that normal rates of reproduction provide populations with protection against threats of extinction in extreme years, because more young are produced than are needed to perpetuate the species. If sustainable yield criteria are based on acceptable take levels in normal years, takings could affect the reproductive potential of populations, making them less resilient in the face of extreme conditions of cold, drought, etc. Consequently, some theorists have argued cogently that attempts to characterize sustainable yield should be computed for multi-year periods so that worst-year scenarios are included.

c. Multiple-Species Models. Maximal or optimal sustainable yield models can also be criticized because they normally concentrate on a single or small number of species. Management of any ecosystem for maximizing humanly useful products necessarily favors species preferred by humans. Over time, these manipulations will have a simplifying effect on ecosystems. (Norton, 1983; Leitzell, 1986, Section IV.D) Consequently, there seems good reason to complicate maximum sustainable yield models by expanding concern to all species interacting in systems.

d. Resource Stability versus Ecological Stability. The arguments just presented form a progression. When individuals or societies make decisions about allocation of resources, they naturally favor current benefits over future ones. A simple discounting model for expressing time preference is thereby suggested but, when such models are applied to resource use over extended periods of time, irreversibilities can favor policies that promote destruction of otherwise renewable resources. Concerns of intergenerational equity thereby raised have not been adequately modelled in terms of distributive justice across generations. Therefore, there is reason to favor a cluster of models that begin with an assumption that resources should be protected provided the costs are acceptable. The simplest such models, however, ignore ecological knowledge. As more and more biotic factors such as variability in climate and abiotic factors such as competition among species are factored into the model, it becomes more and more difficult to determine a safe level of exploitation for a given species. Thus, while models designed to set criteria for safe exploitation of

resources constituting biological diversity may provide rough-and-ready guides, they must be used with caution.

4. Summary of Problems Involved in Computing the Role of Biological Diversity in Fulfilling Human Demand Values

While demand values are, in principle, computable at a given point in time, such computations could only be accurately completed with significant inputs of currently unavailable ecological information concerning interspecific dependencies. Even given such information, computations of demand values apply to limited time frames (limited by the extent to which present individuals express demands reflecting a desire for secure means to fulfill future demand values). Neither discounting nor models attempting to operationalize distributive justice across generations have succeeded in correcting for time preference considerations. Attempts to operationalize criteria of sustainable yields across time appear most promising, but accurate predictions require scientific data and models not yet available. Therefore, any quantified statements of the demand values fulfilled by biological diversity must be seen as no more than rough approximations at this point. Unquestioning use of such computations is almost certain to result in ignoring contributory values of species and in undervaluing satisfactions of future demands. Decisions that protect biological diversity and its contributions to the fulfillment of human demand values must therefore rest upon informed, qualitative judgments as well as approximate computations.

B. Problems in Fully Recognizing Nondemand Values of Biological Diversity

Nondemand values will always be undervalued when decisions emphasize current economic growth. Those who believe that elements of nature have intrinsic value argue that these values are not commensurate with human interests and demands, that they do not register on a single scale. (Regan, 1981). Consequently, they cannot be represented by intensities of preferences, and any attempts at quantification will be largely arbitrary.

Similarly, it was shown that transformative values cannot be expressed on the undimensional scale of demand values. Again, over-emphasis on computable demand

values will ignore the role of biological diversity in examining, criticizing, and reforming current values which appear unjustifiably consumptive and materialistic. Intrinsic values attributed to nonhuman living things and transformative values derived from them are, in principle, not expressible as quantified values. Again, the conclusion must be that wise decision making should be based upon recognition of the importance of demand values, perhaps represented by a quantified approximation, but generously tempered by qualitative concerns deriving from a deep understanding of demand values not currently susceptible to accurate quantification because of unavailable ecological information, and of nondemand values which cannot, in principle, be quantified. Wise decisions affecting biological diversity must, therefore, be based more upon qualitative judgment than quantitative analyses.

Part V. Valuation Criteria for Biological Diversity

In this section, several general features of valuation criteria will be discussed, and valuation criteria exhibiting these features will be assessed on the basis of generalizations drawn from Parts I-IV, above. Three approaches to valuation criteria will be discussed: A. the BCA approach; B. the SMS approach; C. the ecosystem approach.

A. the BCA approach attempts to assess the value of a particular species by determining its actual and possible uses and perceived values based on market behavior of individuals supplemented by hypothetical market techniques when necessary. This approach has two advantages: (1) it strives toward a single, quantified value that can be very useful in attempts to assess the costs and benefits (for economic activity) of various courses of action; and (2) it is purely descriptive in that no judgments need be expressed regarding the comparative value of preferences: all individual preferences are subjectively expressed monetarily as intensities.[17]

The BCA approach, however, suffers from a number of weaknesses.

(1) the BCA approach is a species-by-species approach, with each species starting with zero value. Each increment in value must be identified and evaluated. But

it is always impossible to know whether a new use will be found for a species in the future. Further, this approach usually ignores contributory values, as the species supported and sustained by a species under examination are not normally known. Consequently, the role of a species in forestalling ecosystem collapses is unknown, as well. In general, the BCA approach fails to recognize a general presumption in favor of preservation, as reasons to protect each species is generated from specified uses and from actually registered preferences. It therefore risks serious resource loss through the dangers of incremental decision making.

(2) While the value neutral nature of BCA's is an advantage in some situations, it also represents a disadvantage because most citizens lack ecological knowledge on which to base preferences. For example, data shows that most individuals would take few steps to protect nonvascular plant and invertebrate animal species. (Kellert 1986) But since these species often support other species they prefer to protect, the preferences they express, if not criticized and evaluated, may prove self-defeating.

(3) Because BCA approaches emphasize quantifiable values, they exert considerable pressure to quantify values, even though intrinsic and transformative values cannot be quantified in principle, and demand values require unavailable scientific information. Insistence upon quantification of values can lead to a systematic undervaluation of biological diversity.

B. By assuming that preservation options have considerable value and by placing the burden of proof on development options threatening a species or ecosystem, the SMS approach avoids the uncompletable task of specifying and quantifying each use to which the resource might be put. The disadvantage of this approach is that it cannot specify some particular value so that, in close decisions, a sharp dividing line can be specified between options that justify development even at some expense to biological diversity and those that do not. In other words, the central rule of the SMS approach, that resources should be preserved provided costs are not unacceptably high remains a vague criterion.

Besides avoiding impossible requirements of quantifiability and instituting a very valuable presumption in favor of preservation, the SMS approach can also be used to transcend the species-by-species strategy. The SMS criterion can be applied to questions concerning the preservation of individual species, but it is also applicable to ecosystems and habitats. This is a decided advantage.

C. Ecosystem approaches, which evaluate ecosystems rather than individual species, have many advantages in providing an adequate accounting of the values of biological diversity. All wild species are integrated into ecosystems. It is there that they compete and adapt, drawing upon as well as sustaining other species. In these contexts, they will evolve new characteristics which may prove useful to humans in the future. Species-by-species approaches fail to consider these values.

Ecosystem services cannot be adequately valued by paying attention to species independent of their interactions with other species. Further, aesthetic enjoyment is enhanced when species are encountered in their natural habitat, and the ecosystem approach is more likely to succeed in capturing full aesthetic value.

Likewise, encounters with wild species are more likely to affect value preferences (have greater transformative value) when encountered in a natural setting. And, finally, intrinsic values of wild species, if these can be defended, would almost certainly be taken to imply that these values can only be fully recognized and protected if the species in question continues to exist in its natural habitat.

The values of biological diversity are not accurately quantifiable. This is unfortunate, because governmental decision makers have applied BCA approaches to an increasing proportion of resource use decisions. Any serious attempt to protect biological diversity must recognize its qualitatively expressible values; attempts to enforce quantifiability lead necessarily to an undervaluation of this resource. Recognition of this fact need not make decision making more difficult. The SMS approach urges that resources such as species and ecosystems should be preserved unless the costs are unacceptably high. That rule places a burden of proof on all proposals that will predictably decrease diversity. In the absence of ecological

knowledge necessary to assess demand values, in view of strong arguments that there are qualitative values, either transformative or intrinsic, the SMS decision rule is most likely to protect the value of biological diversity.

Part VI. Effectiveness of Groups

It was shown in Part I that concern for biological diversity must encompasss variability in ecosystems, as well as species. This implies that the problem of preserving biological diversity is much broader than the problem of protecting endangered species.

Federal agencies (Interior, Commerce) charged with protecting endangered species address only the symptoms of rapid conversion of natural systems. These agencies pursue a species-by-species approach to preservation, in that species are identified first, and then critical habitats instrumental to protecting designated species are chosen. This role is important as a stopgap against unnecessary losses, but these agencies are not charged to protect biological diversity in the broad sense.

A comprehensive plan would retain the Endangered Species Office but with expanded duties to oversee ecosystem protection. Perhaps less effort should be expended in the listir process. These efforts would be re-directed toward a comprehensive plan to protect habitats.

The actual protection of habitats, should take place through the Wilderness Bill, through a more preservation-oriented plan for the use of public lands, and by co-operation with the Nature Conservancy and other private sector habitat protection groups.[18]

The crucial role of habitats in the protection of biological diversity cannot be over-emphasized. All of the diverse values discussed above, both quantifiable and not, are only (or more fully) protected when habitats are preserved. (Leitzell, 1986; Norton, under review, Chapter XIII)

NOTES

[1] Some authors insist that diversity measures take relative abundancy of species into account. (MacArthur, 1965, pp. 511-515). Others would index according to the phylogenetic distance between species represented. For generally skeptical remarks, see Hurlbert, 1971.

[2] While species counts can, again, serve as a rough indicator of total diversity (Whittaker, 1972, p. 232), other factors can also be important (See note #1).

[3] While terminology is not uniform, related dichotomies are operative in Ehrenfeld, 1981, in Ehrlich, 1981, Ch. 3; and in Myers, 1979, 1983, p. ix.

[4] Terminology is not uniform on this point. It is agreed that is is important to distinguish two senses of independent value. An object can be said to have strongly independent value if it has value and if this value depends on nothing else for its existence; or, it can have weakly independent value if it has value and if this value does not depend on the values of any other valuer. In the strong sense, nonhuman species would have intrinsic value even if humans had never existed. In the weaker sense, independent value depends upon the existence of conscious valuers, but not upon the specific values they hold. Some writers use the term "inherent" to refer to the weak sense, reserving "intrinsic" for the strong sense. (See Frankena, 1963, p. 66.) Good arguments suggest that the relevant ethical question concerns whether nonhuman species have independent value in the weak sense, because that sense is no doubt sufficient to imply human obligations. Nevertheless, engrained usage refers to "intrinsic" value as any value independent of humans. For a full discussion of these points, see Attfield, 1983.

[5] See below, Section IIIC.

[6] See Bentham, 1961, Chapter 17. Despite his formal statement that all sentient beings must be counted in the utilitarian calculus, Bentham did not, in practice, follow this requirement and, later in his life, seems to have deserted it altogether.

[7] As noted, this paper will not treat nonanthropocentric transformative values (theories in category II, ii, Figure 1)

[8] See below, Section III. B.

[9] Introduced in Section II. B.

[10] Above, Note #4.

[11] Tom Regan, for example, says:

> The point preservationists must keep in mind is that to ask how many caribou lives equals in value the disvalue of how much economic loss is unanswerable because it is an improper question. It confounds two incommensurable kinds of good, the inherent good of the caribou with the noninherent good of economic benefits (Regan, 1981).

[12] Because BCA terminology is not uniformly applied, no claim is made that my criticisms apply to all systems of analysis grouped under that category by others. Systems of analysis which do not fulfill my strict definitions are included in my more general category of economic analyses.

[13] A well-known biologist has asserted that, for every plant species that goes extinct, fifteen animal species can be expected to follow (Raven, 1982, p. 295). This figure is surely high, as it takes no account of ecosystem redundancy and accomodation to a new ecological situation. His general concern, nonetheless, is no doubt well founded.

[14] This concern is eloquently voiced in the Ehrlich's "rivet-popping analogy." Ehrlich and Ehrlich, 1981, pp. xi-xiv. The claim is not that each extinction threatens a collapse, but that each one reduces the redundancy which makes such a collapse less likely. In a situation of limited knowledge, however, these reductions in diversity increase the risk of collapse.

[15] Hardin, 1968, is often interpreted in this limited manner.

[16] See, for example, Kavka, 1975. It is too early to say whether an inter-generational model will be developed which adequately accounts for temporal asymmetries in decision making and operationalizes the intuitive sense of justice. It is safe to say that philosophers, at present, are far from providing a coherent specification of such a model. Norton, 1974b, summarizes some of the reasons not to be sanguine about future efforts.

[17] This point is sometimes characterized by saying that human preferences are "sovèreign." See, for example, Dennis Mueller's account of Kenneth Arrow's rule of the "unrestricted domain." (Mueller, 1979, p. 194). Also see Norton, under review, Section XI. 2.

[18] See Hoose, 1981, for a description of the Nature Conservancy's comprehensive ecosystem approach.

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An Ecological Perspective on the Valuation of Biological Diversity

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University of Washington

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AN ECOLOGICAL PERSPECTIVE ON THE VALUATION OF BIOLOGICAL DIVERSITY

by

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Congress of the United States
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ABSTRACT

The values of biological resources are examined from (a) commercial/utilitarian, (b) recreational/aesthetic, (c) scientific/educational, and (d) ecological/evolutionary perspectives, with emphasis on the latter two categories. Most species of organisms do not now have nor are they likely to have in the future, direct market values. Nonetheless, they do have extreme utilitarian values that are not traded in markets. The stock of living species will doubtless continue to be exploited extensively for products of direct market value. Aesthetic and recreational values attached to species are based on criteria of rarity, impressiveness, similarity to people, unusualness, and, at a community level, the richness of species. These criteria for valuation do not correspond closely to those developed on utilitarian or scientific bases, so that continuing conflicts in establishing values are to be expected.

The rich arrays of living organisms are of great value in science and education because they demonstrate the amazing variety of methods organisms possess for coping with variable and often unfavorable physical and biotic environments. They are also the raw materials for studies of the adaptive significance of the traits of organisms and for our attempts to understand how the living world evolved. In this context, fossils are an important source of information and their preservation should be given greater weight than it currently is. Biology courses draw upon information gathered from thousands of species of organisms, livng and extinct, to help make people aware of our rich biological heritage and to alert them to the nature and extent of losses to the quality of human life to be expected if massive extinctions of species occur.

Ecosystems perform many different services that contribute to the quality of human life. The ecological values of species can be approached by determining

the effects of their loss on the functioning of the assemblages of species that remain. Ecological theory is best developed for considering the losses of single species. Some species (keystone species) exert strong effects on the communities in which they live. Because their loss results in major changes in functioning of those systems, attention needs to be directed toward identifying keystone species and taking steps to reduce the probability of their loss. The types of species that are especially extinction-prone are generally recognized (top carnivores, species with poor dispersal and colonizing abilities, local endemics, species with colonial nesting habits, migratory species, species dependent upon unreliable resources, and species with no evolutionary experience with similar perturbations), and management can be directed preferentially toward them.

Ecological information is useful at all stages in managing the store of biological resources. In particular this information is of value in identifying species, providing us with the list of what is available to be preserved and where they are found; in eliminating pseudo-options, that is, in pointing out which combinations of species are not really viable; in estimating conservation costs, by determining what it takes to conserve different species and communities of species; and in predicting social value of species and assemblages, based on past sources of valuable species and theory that helps to identify where particular traits that may be of value are likely to be found.

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AN ECOLOGICAL PERSPECTIVE ON THE VALUATION OF BIOLOGICAL DIVERSITY

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A "resource" is any material that is of value to people, whether that value is traded in markets or not. Genetic resources or biological resources are organisms of known or potential value to humanity, leaving aside any discussion of whatever intrinsic worth organisms may be considered to have.

In recent years, the problem of evaluating biological resources has taken on a special urgency. While extinctions are a normal part of biological processes, human activities in the last century have accelerated the process to 1000 times the speed of even what occurred during the "great dying" at the end of the age of dinosaurs (Myers 1983). These impending losses have stimulated concern at the highest levels of government (U.S. Agency for International Development 1985). To establish effective policy decisions designed to slow this unprecedented wave of extinctions, information on the value of these vanishing resources is needed. This paper presents a perspective on biological resources that emphasizes ecological values.

Living organisms are valued by people for many reasons. The evaluative criteria used are influenced by a person's age, sex, experience, and socioeconomic status, and they also vary among cultures. Current values are also the product of a long history during which the nature of interactions between people and other

living organisms and the attitudes of people about those interactions have changed dramatically, both within and between cultures (Thomas 1983). Nonetheless, certain types of values have persisted over long time periods, particularly in relation to uses of species for food, fiber and medicines. These persistent patterns provide the basis for predictions of the probable future value of species.

We find it useful to divide valuation criteria into four major categories - (1) Commerial/Utilitarian, (2) Recreational/Aesthetic, (3) Scientific/Educational, and (4) Ecological/Evolutionary. These categories, or any others we might erect, are not totally distinct, but they offer a framework for viewing the valuation of species. After dealing with each of them in turn, we will provide a synthetic overview that points to common threads among the different criteria and highlights where they are the most different.

Cutting across these four major categories of valuation criteria are two broad types of value that are usefully distinguished. The first is the direct value of the focal organism. Such values include the market value of a species as well as its value aesthetically and scientifically. The second value is an indirect one that depends upon the fact that the focal species may be vital for the support of something else that is of direct value. The "something else" could be another species or a nonliving process such as microclimate modification or air purification. Such indirect values are important in all major categories of valuation. A species may be valued because it is a

key prey species for another organism that has market or aesthetic value. Ecosystem stability may depend upon the presence of species with no direct value in themselves. Direct values are more readily perceived, studied and quantified than are indirect values and they are, consequently, much better understood. As a result, we are less likely to inadvertently lose species of direct value than to lose species whose value is indirect and unrecognized.

Economists suggest that the creation of markets for some of these values may hold the key to their conservation in the face of competing uses for the lands that support them (Goldstein, in press, NAS 1983). This is undoubtedly true under certain conditions (where the species reproduces quickly, for instance) but the creation of market values has led to accelerating the rate of depletion of some biological resources with long pre-reproductive periods and low rates of reproduction (e.g. ornamental cacti, whales: see Clark 1973).

Among the non-market means of conservation, biological preserves have had the widest usage. In economic terms, setting aside parks and reserves carries with it high opportunity costs because other uses of the land must be foregone. Much of the land set aside for conservation and preservation of species in temperate regions is on areas of low value for alternative purposes, which is why they were established there in the first place. Population pressure and the lack of more economically productive alternatives, however, have jeopardized even such marginal lands in many tropical countries, and conversions to

agriculture and forestry have been rapid. The countries possessing these land-based resources can ill afford to forego those uses. Moreover, the potential economic benefits to be realized from preservation of species are widely shared among the countries of the world, and many if not the majority of the benefits are likely to be captured by the developed countries of the temperate zone. The need to develop schemes for sharing the costs, as well as the benefits, more equitably, is one of the most important problems confronting the modern world.

Most of the values which we will discuss are not priced in traditional markets, but may nonetheless be economically real. Species or genes may have commercial and scientific values, reflected in their contribution to improved productivity and understanding of how the world works. They have aesthetic and existence values, reflected in the willingness of people to pay to preserve them, to look at them, to bequeath the opportunity to see them to their descendents or simply to know that they are there. Such non-marketable values are difficult to quantify, although a number of methods have been used by economists to try to estimate them (Bockstael, Hanemann and Strand 1984, Hanemann 1983, Fisher and Hanemann 1984, Krutilla 1967, Weisbrand 1964). All of these methods have their particular problems and most of them have been applied in only a few instances to assessments of the value of species (Brown, in press). Rather extensive catalogues of estimates of values of species have been provided by Myers (1983, 1984) and Oldfield (1984) but most of these estimates are speculative. They are, at best, only suggestive

of the future research that must be done if societies such as ours are to be able to rigorously assess the true value of living resources, and, hence, to make rational decisions concerning the quantity of resources that ought to be allocated to preservation of species.

One further distinction may be important in understanding the discussion that follows. On one hand there are values directly associated with the organism being conserved, whether they be direct consumptive values, amenity values, ecological values or option values. In addition, however, there are the values associated with the knowledge needed to better insure in the conservation of organisms being valued under the previous criterion. Investment in knowledge to improve future choices is a distinct and often unappreciated part of the total investment process of societal resources. Much of the rest of this essay is concerned with the value of scientific studies in making the criteria for those investments more precise.

COMMERCIAL/UTILITARIAN VALUES

The most easily quantified and probably the most discussed aspect of biotic value is that which comes into the commercial sphere. The economic importance of these generally consumptive uses has recently been the subject of several excellent reviews. (Oldfield 1981, 1984, Myers 1979, 1983, 1984, Fisher 1981) to which the reader is referred; we will only briefly touch upon the major points here.

The actual and potential economic productivity of the world's diverse biological endowment, in uses ranging from subsistence foraging to genetic engineering, can hardly be overstated. While hunting in the industrial world is essentially recreational in nature (see below), subsistence foraging provides a major albeit non-monetary component of many developing economies. Commercial foraging can also be economically important; many useful species have proved impossible or expensive to raise in captivity. The supply of fish, wood, and many species of ornamental plants, pets, medical research subjects, shells and even foods (e.g. the southeast Asian Mangosteen, NAS 1975) remains largely dependent on wild production.

The wilds also contain a host of species that have great potential as new food and industrial crops, including desert, ocean, rain forest based food plants, and commercially promising sources of fiber, pulp, biomass, waxes, rubber and even petroleum. Wild germplasm may also be key in the continued improvement of present crop species, a process worth approximately $1 billion per year in the U.S. alone (Myers 1983). Biological control techniques used against agricultural pests and weeds also rely heavily on tapping biological diversity, resulting in substantial economic returns. Many unexploited and even undescribed plant and invertebrate species hold the promise of important medicinal properties, and an impressive list of discoveries in the recent past gives us reason to be optimisitic about future prospects (Oldfield 1984). Even if the continued development of genetic engineering technology eventually eclipses

the prospect of direct cultivation of such species, their value as repositories of useful genetic information will be all the more important (Balandrin, Klocke, Wurtels and Bollinger 1985). Table 1 provides a classification of market values of wild species and germplasm.

Table 1

A Classification of Market Values for Wild Species and Germplasm

Type of Value	Examples
FOOD	Harvested from the wild Potential new agricultural species Germplasm for improving existing domesticated species and races
HEALTH	New medicines Research subjects
INDUSTRIAL PRODUCTS	Wood Fiber Resins, oils, waxes, rubber, etc.
BIOLOGICAL CONTROL OF PESTS	
PETS AND ORNAMENTAL PLANTS	
FUR AND FASHION	
OTHER VALUES	Watershed preservation Rehabilitation of disturbed areas

IDENTIFYING UNCERTAIN RESOURCES

Identifying commerically valuable genetic resources remains an art form as much as a science. Improving our abililty to pinpoint plants and animals of medicinal, industrial or food

value would greatly increase the value of the resources themselves. The most important contribution to this identification process should probably come from anthropologists and ethnobotanists tapping the rich and endangered stockpiles of information in traditional cultures. Where such is not available, however, ecological theory may prove helpful. The evolution of plant secondary compounds (which form the basis of most plant based drugs and resins) has been the subject of considerable discussion in recent years. Plant-herbivore theories proposed by Feeny (1975) and Rhoades and Cates (1976) suggest that common, conspicuous, and long lived plants should tend to develop "quantitative" defenses (such as tannins) which, though expensive, deter even the specialized herbivores that evolve to handle their defenses. Rarer, less conspicuous, and shorter lived plants, on the other hand, have less potential for supporting specialists, and so may get by on the energetically cheaper "qualitative" defensive chemicals, thereby deterring generalist herbivores. Plant-herbivore interactions are increasingly recognized as being very dynamic with both plant and herbivore responding over sometimes very short time spans to changes in the other (Rhoades 1985). If we enter into the equation what is known about inter-habitat differences in herbivore pressure (generally highest in the tropics) and tissue replacement costs (highest in dry and nutrient poor environments), the groundwork has been laid for development of a comprehensive theory of plant chemistry that can help us pinpoint the most likely prospects for finding particular classes of medicines or industrial

products and how to induce plants to produce more of them.

Food. No profound ecological theory is needed to identify wild relatives of crops and livestock presently in use, although improved species inventories of little known biological communities might pay dividends on this front. In the search for potential new agricultural species, however, ecological considerations might be instructive. Potential domesticates should have at least some of the following properties:

a) The organism should be edible, at least in part, or must be capable of being made edible with simple processing. This places less constraint on potential livestock species than it does on plant species. Among the species offering significant amounts of edible materials, several groupings emerge. Among leafy crops, we rely primarily on species with either low levels of defensive chemicals, or with specialized "qualitative" defenses against herbivores very different from ourselves. Thus, promising new leafy vegetables are likely to be found among what Feeny (1975) termed "inconspicuous" species, ones which are rare, perhaps successional, and generally short-lived. Another group of potential crops are those with fleshy fruits, developed as a seed dispersal mechanism. Such adaptations are particularly common among "fugitive" species, which quickly colonize open habitat patches. Nuts and grains, on the other hand, tend to come from species requiring large embryonic energy reserves for successful establishment, either because intense competition (as occurs among climax species in a succession) or due to harsh

physical conditions. Tubers are also important as storage organs under similar harsh conditions (Baker 1964).

b) Potential crop or stock species should be ones that function well at high population densities. Gregarious animals, for instance, more readily adapt to the crowded conditions of agriculture than do territorial species, and they should also be easier to keep track of and harvest. Gregariousness may be an evolutionary response to visually hunting predators (Vine 1971, 1973, Hamilton 1971), and seems to be most common in species from open habitats, such as savannas or clear water (Geist 1974). Similarly, among plants, monocultural plantings could be most favorable to species with evolutionary experience with intense intraspecific competition, that is, abundant species or ones naturally occurring in clumped distributions. The use of polyculture, however, may reduce the importance of this effect. In both plants and animals, mixtures of several species can often out-produce single species cultures, perhaps due to a reduction in competitive intensity.

New crop or livestock species that make use of habitats and resources which are not currently productive would be especially valuable. New crop plants capable of being grown in arid, humid, cold, hot, or shaded environments would expand the potential land base available for food production. Similarly, ungulates invulnerable to the tripanosomes spread by tsetse flies could dramatically increase the agricultural productivity of central Africa (Oldfield 1984).

The consideration of such biogeographic and ecological points may allow the pin-pointing of species of important agricultural potential, especially when considered in the context of existing folk utilization patterns.

Biological Control. While biological pest control has been very successful in certain cases (Rice 1983), its usefulness has been hampered by the difficulty of identifying effective control agents. As a result, the majority of introductions either fail to establish themselves or, even if they do, they fail to provide effective control (Clausen 1978). The criteria used to identify potential control agents *a priori* have normally been (a) does the species prey upon the organism to be controlled? and (b) can it tolerate the physical environment in the area of the proposed introduction (DeBach 1974)? Ecological considerations may help make such choices more dependable. For example, knowledge of the feeding behavior of the control species may help us predict whether or not it will be most effective at high or low prey densities. Knowledge of feeding rates as a function of age and temperature can allow more precise calculations of the number of prey likely to be ingested by each predator and how that number will vary with environmental conditions. Information about the relationship between feeding rates and reproductive rates of predatory insects and other arthropods enables estimates to be made of the potential rates of population growth of control agents (Hassell 1980), Waage and Hassell 1982). These considerations, which are based on extensive recent information on foraging ecology and population dynamics, if applied more

consistently in the future, should result in a much higher percentage of success in biological control efforts than has been true in the past.

RECREATIONAL/AESTHETIC VALUATION OF SPECIES

Consumptive and nonconsumptive uses are involved in the recreational and aesthetic values associated with species. The prime motivation of such consumptive wildlife uses as hunting and fishing is recreational. In highly technological societies, such activities cannot be justified in terms of the economic value of the food consumed. Indeed, many people fish with barbless hooks which decrease the probability that a fish will be caught, and many of those same people routinely return to the water the fish they have caught. Among hunters, many prefer to use methods such as bow and arrow hunting because it is more challenging, despite its much lower rate of success. Thus, both consumptive and nonconsumptive use of wildlife rest primarily upon the emotional satisfactions surrounding being in natural habitats and interacting with other species, whether or not the individuals are returned in the form of carcasses, skins, photographs, or memories.

Although consumptive and non-consumptive uses of species do not differ in kind, they do differ substantially in their effects on the resources. Even with intensive management, the number of animals that can be taken or the number of plants dug up in a given area is severely bounded on its upper limits. Indeed, with increasing pressures on land and consequent shrinking of natural

habitats, the stock of exploitable individuals is likely to decrease rather than increase in the future. Therefore, since a given individual can be shot or picked just once, whereas it can be photographed or observed many times, the relative importance of nonconsumptive uses of other species has gradually increased, and will likely continue to do so (Shaw and Mangun 1984). In accordance with these shifts, many departments of fish and game have already changed their names to departments of wildlife (Nature Conservancy 1977).

Procedures by which consumptive uses of species pay for some of the costs of preserving them have been implemented for many years in the form of hunting and fishing licenses. Costs of preserving species for nonconsumptive uses must also be borne in part by the users but in this case, because the user group is more difficult to identify, free-loading is likely to be prevalent and difficult to control. Nonetheless, several promising methods are now being used in different states, including specialized license plates and state income tax check-offs (McCance 1985). More attention needs to be given to development of those and other methods because through them people have an opportunity to demonstrate to political leaders the strength of their commitment to the recreational value of species.

Quantitative studies of the criteria by which people value living organisms for recreational and aesthetic purposes are rare. Nonetheless, it is clear that the following criteria are especially important.

(a) rarity - a rare flower or bird is much more highly valued than a common one. This is true even if the species is actually very common in parts of its range but rare in the area where people are looking for it. For example, the Ross's Gull that spent part of the winter of 1980 at Newburyport, Massachusetts was visited by thousands of people, some of which flew thousands of miles simply to view the bird. This was not because the Ross's Gull is a rare or endangered species or because the individual was a member of a local race, but because it is rare where most observers pursue their recreational activities.

It takes only a brief glance at the monthly publications of local and state bird watching groups to realize that most of the attention of bird watchers is paid to rare species, species outside their usual ranges, or species present at times of year when they are normally absent. The fact that such individuals are ecologicallly and evolutionarily much less interesting than individuals in the main part of a species range does not diminish the recreational pleasure that they provide.

b) Impressiveness - large, spectacular animals and plants are much more highly valued aesthetically than are smaller and drabber species, even if the latter are rare and the former common. Spectacular species, such as the California Condor, Whooping Crane, and Grizzly Bear incite awe, admiration, and excitement in observers. Many such large species are potentially dangerous and, indeed, were dangerous during earlier periods in human history. It is no accident that large, dangerous animals play an important part in the mythologies of many ethnic groups

(Mundkur 1983) and that animals such as snakes are almost universally given special attention in myths and architecture (Wilson 1984). Tourists in East Africa spend the great majority of their time looking for large predators such as lions, leopards and cheetahs. The success of the World Wildlife Fund in raising money for conservation efforts in all parts of the world depends in large part on the targeting of efforts towards large, spectacular species. The use of the giant panda as the logo symbol is believed to be a most fortunate choice (World Wildlife Fund 1982, 1984). The panda is a very unusual animal and it is also among the largest of the "warm cuddly" animals.

(c) Similarity to humans - other primates have more appeal to people than any other group of animals, perhaps because they provide the clearest mirror into our own behavior and remind us, consciously or unconsciously, of our evolutionary unity with other living organisms. Appeals for land purchases to save primates are especially successful (World Wildlife Fund-Annual Reports). Mammals in general excite interest as do birds because of their bright colors, flight and diurnal habits. It is much more difficult to motivate people about reptiles and amphibians, and fish, and the number of people that become emotionally involved with most invertebrates is rather small. There have been successful efforts to save butterflies, especially in Britain and the United States (Pyle, Bentzien and Opler 1982), and corals and certain molluscs do excite interest. However, most invertebrates lack much aesthetic appeal unless individuals have been educated with respect to the many interesting features

of their behavior, social organization, ecology, and interactions with other species.

(d) Unusualness - a species which is the sole representative of a group of organisms or which is a highly different member of a larger group, attracts special attention. The Galapagos Marine Iguana is of special interest because it is the world's only marine lizard. Flamingoes attract attention not only because they are large and spectacular but because of their unusual way of feeding in which small organisms are strained out of the mud while the head is held upside down. Australian megapodes that incubate their eggs in piles of rotting vegetation where decomposition rather than the body of the parent bird provides the heat, have high uniqueness value. So do echidnas and duck-billed platypuses, the only mammals that lay eggs.

(e) Species Richness - often value is attached not to particular species themselves but to the number found in a particular region. Many people keep life lists of the species they have seen. More ardent listers may have yearly lists, state lists, county lists, continent lists, and the like. "May Days" in which groups of observers compete to determine which one can see the largest number of birds species in one day are commonplace in the United States. Brochures advertising the attractions of places, with the purpose of luring tourists, often explicitly mention the large number of species that can be found in those areas. The abundance of such evidence clearly shows that richness per se has high aesthetic value. People find their lives enriched by opportunities to see a wide variety of species.

Most species with high recreational and aesthetic values do not participate in markets in the narrow sense of the word. Most of them are unlikely to be involved in markets at any time in the future. Nonetheless, the techniques developed by economists to estimate economic value of such species, as discussed briefly in the previous section, reveal that the economic implications of recreational use of those species are substantial.

The Roots of Aesthetics. The formation of strong aesthetic judgments, often without conscious reflection, is a basic and pervasive feature of human behavior. Although these judgments are obviously influenced by the past experiences of individuals and of the culture of which they are a part (Thomas 1983), there is increasing reason to believe that there are important evolutionary components to such judgments. One promising avenue of analysis has been based upon habitat selection mechanisms (Appleton 1975, Orians 1980, 1985, Wilson 1984). Other foundations may include relationships with potential prey and predators, but little attention has been given to these possibilities. It is too early to know the extent to which human genetics influences aesthetic judgments but the rapid developments in this area of investigation may open up new possibilities for predictive evaluation of genetic resources.

SCIENTIFIC/EDUCATIONAL VALUES

Research and education in the biological sciences require extensive use of living organisms. These two uses of organisms

are, of necessity, intimately interrelated. Nonetheless, we will discuss them separately to enable our remarks to have a greater focus than would otherwise be possible.

Scientific Value of Species

Living organisms are of value in science both for the information they contain, that is what they tell us about how the world works and how it came to be the way it is, and as subjects to be used in actual research. Biology is concerned with three major types of questions: (1) how living organisms function, (2) the adaptive significance of the traits of living organisms, i.e. why they evolved the properties they have rather than others which might be imagined, and (3) how the living world evolved from simple, nonliving ancestors into the complex array of species found today in different parts of the Earth. To explore these questions biologists use carefully focussed observations, experimentation, and the comparative approach. Full answers to questions normally involve use of all three methods even though individual scientists usually concentrate their skills and efforts in one or two of them.

How living organisms function. Living organisms possess an amazing variety of methods of coping with variable and often unfavorable physical environments, finding places in which to live, locating food, avoiding becoming food for other organisms, finding mates and reproducing. The very fact that there are millions of species of living organisms rather than a much

smaller number, suggests that there is no single best solution to life's problems. Therefore, understanding the ways in which organisms function requires the study of many different species. This is as true in applied areas of biology, such as medical research, as it is in basic fields such as comparative physiology. Indeed, a recent report of the National Academy of Sciences (NAS 1985) strongly recommends the use of a much wider variety of species in medical research than has traditionally been the case. The use of more types of organisms can result in substantial savings (mammals are very costly to raise and experiment with), reduced opposition from animal-rights groups, and can lead to models better suited for exploring underlying mechanisms than are the more complex mammalian systems that have dominated medical research for many decades. The recommendation of the NAS panel is based upon the fact that underlying the richness of biological diversity are many common mechanisms that can profitably be studied in simple organisms.

The traditional approach in medical research, called "one-to-one modeling" by the NAS panel, is to consider the research animal as a surrogate for humans and to pick a species in which the disease appears to function similarly to its behavior in humans. In "many-to-many modeling," the approach recommended by the panel, the researcher breaks down the disease into its component parts and for each component seeks useful analogues throughout the living world. If these practices are adopted, the number of species of living organisms used in medical research is likely to increase dramatically.

Why living organisms have the traits they do. Why questions are concerned with the adaptive significance of the characteristics of organisms. Rather than probing into the underlying mechanisms leading to those traits, this research is concerned with demonstrating how possession of some trait improves survival and reproductive success of its bearers. To answer such questions there must be variability among individuals or species in the degree to which they exhibit the traits in question and/or in the types of environments they inhabit so that survival and reproductive success can be compared.

Comparative analysis is a way of doing science that is specifically designed to help us understand why the traits of living organisms have evolved as they have. Since comparative methods are basically non-experimental, "control" is achieved by attempting to randomize the influence of potentially confounding variables by comparing organisms of diverse types and in diverse environments. Moreover, nearly all hypotheses about the functional significance of traits are statistical in nature, that is they postulate that x has been an important selective factor influencing trait y. Only in their most extreme, and unlikely, form do such hypotheses state that x is the only influence on y. Therefore, such hypotheses must be tested by employing a large number of species and different environments. To the extent that species are lost or their ranges seriously reduced, the options open to the scientist are correspondingly reduced.

For those traits that are distinguishable in preserved specimens, museum collections of organisms are an important resource for comparative research. Such specimens preserve a record of the distribution of the traits of interest among individuals of different locations, ages, and sexes. They are being increasingly used to test hypotheses about the selective pressures on the traits of living organisms that would be extremely difficult to test by other means.

Similarly, reserves where assemblages of species typical of those present during the more recent evolutionary history of the component species are maintained are vital for understanding the significance of many traits of organisms. Traits of animals adapted to the presence of larger mammalian predators cannot be studied in environments lacking such predators. The characteristics of fruits of a number of Central American trees may have evolved in relation to the presence of gomphotheres that ate the fallen fruits and dispersed the seeds (Janzen and Martin 1982; but see also Howe 1985). The importance of large mammals such as elephants for dispersal of trees with similar fruits in Africa enables us to infer something about trees in areas where the former larger dispersers are no longer present. Large reserves are essential components of the scientific study of adaptation, in addition to being necessary for the preservation of the component species themselves.

The extent to which many biological disciplines depend heavily upon the availability of a diverse array of species is exemplified by the fact that standard textbooks commonly refer to

hundreds of species in the process of illustrating general biological principles.

How the living world evolved. The study of macroevolution, the broad scale patterns of evolution over millions of years, is an exercise in historical science. As such it is primarily non-experimental in nature. It uses two primary sources of data. One is the array of living species whose traits can be measured. Given the rapid development of very precise techniques for measuring the detailed genetic structures of species and the amount of difference among them, the underlying genetic bases of those traits is now being explored. Among the newly developed powerful techniques for determining evolutionary relationships are comparing sequences of amino acids in proteins, immunological reactions among species, electrophoresis, and, most precisely, the structure of the genes themselves, the nucleotide sequences. The latter are being determined in several ways (Mueller and Ayala 1982, Nei 1973), the most important of which is cleavage of DNA and RNA into short sections by the use of enzymes that recognize specific nucleotide sequences which are then separated electrophoretically.

The second source of macroevolutionary information is the deposits of fossil organisms that have formed under circumstances where the bodies of organisms are not decomposed when they die but are preserved in various forms suitable for study and identification. These fossil beds provide the only source of information about the places where different species evolved,

when they evolved, and when different evolutionary lines separated from one another. Therefore, fossil deposits are a vital component of the biological resources available to scientists studying the course and patterns of evolution on Earth. The scientific value of an organism does not cease with its death, and preservation of fossil beds should be regarded as seriously as the preservation of living organisms (MacGinitie 1953, Stanley 1979).

Organisms that are physiologically or taxonomically unusal are particularly high in their scientific and educational value. Such species may represent the result of unusual selective pressures, isolation, or uncommon initial conditions. Taxonomic outliers may serve as "living fossils," relics of formerly more abundant groups that can help unravel details not preserved in the fossil record; or they may represent new adaptive leaps, giving us evidence about the evolutionary process. In combination, such traits provide scientific rationale for preserving the last species of a genus or family as opposed to preserving some species in a group with many other species in it. Thus, the preservation of the Tuatara (Sphenodon punctatus), a rare New Zealand reptile that is the last remaining species of an entire order of reptiles, may be a particularly high priority even though it is neither particularly attractive nor economically productive. In addition, the traits that make it unique evolutionarily are not very obvious by looking at the animal so that it does not have high aesthetic uniqueness value to go along with its scientific uniqueness value.

Genetic techniques are being developed that can help greatly in determining the actual distinctness of extant species so that species which are really very unique genetically but not phenotypically very different from other species are not undervalued by scientists because they have failed to identify, by more traditional taxonomic techniques, the real distinctness that exists. While there continue to be problems in applying current measures of genetic distance to the measurement of taxonomic distance, the much improved phylogenies that are now being constructed for many groups of organisms should help greatly in identifying unique species likely to be missed by traditional techniques.

This brief account stresses the importance of the existence of a large number of species for all of the major fields of biological research. This importance is destined to increase in the future in all biological disciplines. Biologists typically spend much time deciding which species or groups of species would be best for testing a particular idea. Criteria used in making such selections include length of life span, size, adaptability to laboratory conditions, observability, cost of maintenance, possession of particular traits, and participation in certain interactions with other living organisms. The greater the number of species preserved, the greater the range of options open to the scientists of today and in the future. This is equally true for applied and basic biological science.

Educational Value of Species

In contrast to the past when biology courses concentrated upon a few "typical" species for the study of anatomy, physiology, and ecology, modern science education uses an increasing array of species to help give students a better appreciation of the many different ways in which living organisms have evolved to solve the problems of living in a world of less than benign physical and biological attributes. Our understanding of human existence and our own place in the world is greatly enhanced by knowledge of the many different organisms that share the planet with us and which have evolved under the influences of the same selective pressures that have molded our own species. The proper understanding of people requires a reasonable understanding of the lives of other organisms as well.

Education also serves to increase the value of other species by making people aware of the wealth of organisms that exist in the world. People in urban environments do not encounter many species in the course of their normal daily lives. To them food comes from grocery stores and other natural plant and animal products from different types of stores. They generally do not realize how many plant and animal products are a part of their lives. They often do not know that the existence of many species is being threatened by human activity. They cannot possibly be concerned about the loss of a species of whose existence they are unaware. Those of us who know that eastern North America was home to millions of Passenger Pigeons and Carolina Parakeets, feel a deep sense of loss over the disap-

pearance of these spectacular birds. People unaware that these birds ever existed cannot feel such losses.

The primary reason for stimulating a sense of regret over the extinction of species is to alert people to the fact that many other such losses, some of which can be prevented, will occur during their lives. Only if they are sufficiently motivated will appropriate action be taken soon enough. The value of species in scientific research and, through it, products of value in human commerce, exists whether or not people are aware of the sources of those benefits. Therefore, the losses of those species will negatively affect people who might well choose to avoid those losses if they were aware they were occurring or might occur.

ECOLOGICAL/EVOLUTIONARY VALUE

People, like members of all other species, live in ecosystems that provide the resources necessary to sustain life. People also are involved with the same types of interactions with other species that characterize the lives of all other organisms. We are predators, prey, competitors, and participants in mutualistic interactions, and we work to survive in a variable physical environment. We also have an evolutionary future about which we are concerned. People are not only worried about the quality of the world they will leave to their children and grandchildren, they are also concerned that we not engage in actions that will jeopardize the long term future of our species.

For the purposes of this essay, ecological values of species are those relating to the patterns of functioning of the ecological communities in which we live and upon which we depend. These values are treated in dynamical time, that is over time frames short enough that evolutionary changes in the species in those systems can be ignored. Evolutionary values of species relate to their longer term evolutionary potential. The difficulty, of course, is that rates of evolution of longer lived species are sufficiently slow that, given virtually any discount rate that might be applied, it does not make economic sense to attempt to preserve the evolutionary potential of the species living on Earth with us. This is not the case with many microorganisms that are crop pests or disease organisms of people and their domestic animals. Indeed, rapid evolution of these organisms is a central problem in the development and maintenance of control measures. For most organisms, however, their evolutionary value is primarily informational in nature and was treated in the previous section.

Ecological Value

Although people are unique among living organisms in the extent to which we manipulate the ecosystems in which we live, our dependence upon those ecosystems is not thereby lessened. We are, as a species, probably involved with direct and indirect interactions with more other species than is any other living organism. We are a predator on an amazingly large number of species. It is true that a large fraction of the global human

diet is composed of a rather small number of species (90% of current plant composition relies on some 20 species), but the total number eaten is very large [perhaps 3,000 plant species have been used in the human diet (Myers 1979)]. In addition, we are preyed upon by a large number of organisms, currently mostly small ones that attack us from the inside because we have systematically eliminated large and dangerous organisms over most of the surface of the Earth. We also compete with organisms for food and fiber, and we are engaged in many mutualistic interactions with plants, animals and microbes. Because of the complexities of these interactions, human life depends in many direct and indirect ways upon the kinds and numbers of species of organisms in the ecosystems around us and how they function together.

Natural ecosystems are subjected to a variety of perturbations that differ in kind, intensity, and frequency of occurrence. Some perturbations affect only changes in the abundances of species. Others completely remove one or more species from the systems for long periods of time. Such common disturbances as weather, fires, windstorms, and icestorms, usually affect many species simultaneously, thereby altering many of the interactions among them. The consequences of these perturbations may be expressed primarily in a direct interaction between people and some significant species in the system, or they may be expressed as changes in the overall productivity of the system, its ability to handle wastes, or its stability, all properties that are the result of interactions among many

different species. A useful way of thinking about the ecological values of species is to consider the nature of alterations in ecosystem functioning resulting from losses of single species or groups of them. In this section we first consider losses of single species, then losses of groups of species. Finally we deal with the probability that losses will occur and make some suggestions about research priorities.

Losses of Single Species. One way of evaluating the importance of a species is to imagine the effects of its removal from the system on the functioning of the species that remain. Explicit models of deletion sensitivity have been developed by Pimm and his associates (Pimm 1979, 1980, 1984, Pimm and Lawton 1977, 1980). They have used Lotka-Volterra equations and parameters randomly selected over values designed to reflect both patterns of interactions in the food webs as well as reasonable biological restrictions. From a large set of possible webs, only those with locally stable and positive equilibrium densities for all species were subjected to detailed analyses. From this set, each species was removed in turn and the resulting food web checked for feasibility (all species have positive equilibrium densities that are locally stable), singularity (predators without prey, two predators requiring the same prey, etc.) and stability. The subset of webs that are deletion stable were then assembled to determine the patterns they revealed. These models are all highly artificial because they include neither competition nor mutualism and they deal only with predators that are

much larger than their prey. Their assumption of equilibrium conditions may also make them poor models of many biological systems, where such conditions are rare. Additional studies of other types of food webs will be needed to determine the extent to which the behavior of alternative models is similar to those examined.

Under the conditions included in Pimm's models the following statistical conclusions emerged:

(1) The average species deletion stability decreased with increasing complexity when complexity is measured by connectance, the proportion of possible interactions that are non-zero.

(2) Average species deletion stability decreases with increasing species numbers when connectance is held constant.

(3) Plant species removals cause least loss when the herbivores dependent on the plants feed on a variety of other species.

(4) The more generalized the diet of an herbivore, the less the effect of removing that herbivore.

(5) Predator removal results in more species losses when the herbivores on which the predators feed are generalized than when they are specialized.

(6) Whether a predator is specialized or generalized has little effect on the consequences of its removal.

Removal of predators has much greater effects when prey densities are controlled by their predators (predator controlled) than when prey are close to their own carrying capacity so that

most individuals would have died of other causes had they not been taken by predators (donor controlled). Examples of donor controlled components of ecological communities are all forms of exudates (root exudates, nectar, nutrients leaking from stressed cells, aphid honey dew), the rewards offered in many mutualistic associations (fruits, food resources provided to ants by many plants), eggs, seeds, detritus, sunlight, and plankton for sessile animals.

Species removals can also exert influences through their alterations of competitive relationships. Competition usually occurs among organisms at the same trophic level but in some environments, such as rocky intertidal and subtidal ones, plants and animals may compete with one another for space. Competition is generally stronger among closely related species because they are likely to use similar types of food in similar ways, but competition is also sometimes very strong among very different organisms, such as rodents and ants competing for seeds of desert annuals (Kodric-Brown and Brown 1979, Davidson, Brown and Inouye 1980, Davidson, Inouye and Brown 1984).

Competitive interactions are generally highly asymmetrical, that is, removal of one competitor causes a major effect on the remaining one whereas the reverse is not true (Lawton and Hassell 1981, Connell 1983, Schoener 1983). Usually, but not always, it is the larger of two competitors whose removal produces the greatest response, probably because the larger is able to dominate the smaller in interactions over food and habitat, thereby depressing populations of the smaller competitor sub-

stantially, whereas the smaller can exert its effects on the larger only through resource depression. Nonetheless, the larger, dominant competitors are often the ones most vulnerable to extinction as a result of human-induced perturbations because they require higher resource densities than do the smaller species (Belovsky 1984, Pimm and Pimm 1982).

Mutualistic interactions among organisms do not involve the large quantities of energy captured in predator-prey and competitive interactions but they often influence community dynamics out of proportion to the energy flow through them. Plants are heavily involved with mutualisms with animals and microorganisms because they are sessile and must therefore rely on other agents to bring the sexes together for mating and to disperse offspring. The wind can, and does, perform those services for many plant species, but the majority of vascular plants utilize animal vectors for pollination, seed dispersal, or both (Whitehead 1983). Few plant species have evolved to depend upon the services of a single species of pollinator and even fewer pollinators have become specialized to a single species of food plant. There are advantages from the plant's perspective to attracting specialized pollinators because they are less likely to lose pollen by visiting flowers of other species before they visit another flower of the same species. Nonetheless, floral structures that exclude most pollinators are difficult to evolve and pollinators are in the business of harvesting resources. Their itineraries are determined by efficiency of gathering energy, not efficiency of pollination.

Most frugivores eat a wide variety of fruits during their lives even though a particular species may be especially important during certain times of the year. Many plants, however, are visited by one or just a few species of frugivores and should, therefore, be vulnerable to the loss of just a single species. For this reason, some ecologists have suggested that some frugivores may function as keystone generalists whose activities are essential for the successful reproduction of many species of plants (Howe 1983). On the other hand, recent work suggests that a few plant species bearing fruit during otherwise hard times may serve an important role in supporting a great number of frugivore populations through annual resource shortages (Terborgh 1984).

Plants are also dependent upon microorganisms for fixation of nitrogen but only a few widespread genera are involved and these species are normally present in most environments regardless of the extent to which they are perturbed.

Even though the basic theory of deletion sensitivity of ecological systems is still in its infancy, useful pointers to environmental managers are already available. Species whose losses are especially likely to cause marked changes in the functioning of the system of which they are a part, possibly including great reductions in or extinction of populations of associated species, are clearly high priority species. Current information suggests that such species are especially likely to be found among large frugivores, among plants that fruit during seasons of the year when few other species produce ripe fruit, and large carnivores that are behaviorally dominant and,

therefore, suppress their competitors. Also species that produce the basic physical structure of communities against which all other interractions are carried out; such as vascular plants in terrestrial ecosystems and space-competing animals in many intertidal and subtidal marine systems, are species whose preservation is of great importance. The basic concept is to direct efforts preferentially toward "keystone species," that exert especially powerful effects on ecological communities. Knowledge of these same principles and facts is also of great value in land restoration (Bradshaw 1984, Bradshaw and Chadwick 1980).

Extinction Proneness of Species. To assess the importance we should attach to attempting to preserve a species; we need to know not only the consequences of its loss but also the probability that it will go extinct locally or globally. The following types of species appear to be most extinction prone (Terborgh 1974, Terborgh and Winter 1980):

(a) Top Level Carnivores. These species have low population densities and require large territories or home ranges. They are, therefore, especially vulnerable to habitat fragmentation. They are also especially desirable targets for hunters.

(b) Species with Poor Dispersal and Colonizing Abilities. Human activities usually fragment habitats into small patches within which extinction rates tend to be higher than in larger patches (MacArthur and Wilson 1967, Rappole and

Morton 1985, Willis 1974). Maintenance of populations in these environments depends upon a high recolonization rate of individuials from other habitat patches where the species still survives.

(c) Local Endemics. Species with very restricted ranges, even if they are common where they do occur, are highly vulnerable to localized disturbances.

(d) Species with Colonial Nesting Habits. Most organisms have more restrictive habitat requirements when they are breeding than during the non-breeding season. Consequently many of them gather together in highly suitable sites where they are very conspicuous and vulnerable to destruction by human beings. Among such organisms are seals, sea lions that congregate in favorable pupping grounds, and most marine and fresh water birds that nest in large colonies.

(e) Migratory Species. Preservation of a resident species requires only that one habitat be maintained. Migratory species, on the other hand, are vulnerable to disturbances and habitat destruction in both their breeding and non-breeding ranges. This is of special concern today for species that winter in tropical regions that are undergoing such extensive habitat modifications at the present time.

(f) Rare Species. Rareness, by itself, increases the probability that an organism will go extinct.

(g) Organisms Dependent upon Unreliable Resources. The resources exploited by organisms vary from those that are relatively constant and predictable over time (e.g.

detritus) to those that fluctuate greatly in both space and time (e.g. fruit). The greater the variability in the availability of necessary resources, the more organisms must pass through ecological "bottlenecks" when their populations may be seriously reduced in total numbers and limited to small, favorable areas. Such species are likely to go extinct during one of those bottlenecks for a combination of most of the previous reasons.

(h) Species with Little Evolutionary Experience with Perturbations.

Both the consequences attendant upon the loss of a species and the probability that the species will be lost are important inputs to decisions about allocation of resources to species preservation. Clearly, the highest priority species are those with both a high probability of extinction and severe consequences attending their loss. Lowest priority species are those unlikely to go extinct and whose loss would cause no significant effects on the remaining species. The more difficult cases are ones in which loss is judged to be serious but the probability of loss is low and those where the consequences of loss are only moderate but the probability of loss is high. At present, only rough estimates of these probabilities and values can be given, but if these considerations are factored into decision-making two important purposes may be served. First, the importance of research directed toward improving those estimates will be highlighted and scientists and funding agencies may be stimulated

to direct their efforts toward improving our understanding of these processes. Second, even rough estimates are better than nothing, and policy decisions cannot await the results of long term research.

Losses of Groups of Species. As pointed out earlier, most perturbations do not remove single species from ecosystems but eliminate many species simultaneously. Losses of groups of species seem more likely to lead to major changes in community functioning than losses of single species but there has as yet been no formal analysis of these types of losses. One common pattern is that most of the top carnivores are eliminated from the systems at about the same time leaving the larger herbivores and intermediate predators without significant predators. Since many ecosystems appear to have predator-controlled components (Orians and Kunin, in press), such removals are likely to result in major changes in populations of the remaining species. Also the loss of large herbivores, such as elephants, giraffes, buffalo, and elk, species that under natural conditions exert major influences on vegetation growth forms and productivity, should result in transformed ecosystems. Among these effects should be extinctions of species dependent upon the structure of vegetation caused and maintained by the larger species.

INTRASPECIFIC VARIABILITY AND VALUATION

While most of the conservation literature and the preceding material is devoted to considerations for protecting species,

often the diversity we most value is that found within a species, even where the species itself is in no danger. This is especially true among crop plants, where the fortuitous or deliberate preservation of useful genetic complexes can result in increased yields or improved agronomic properties, which in turn can mean many millions of dollars of revenues. Thus the preservation of diverse genetic strains of maize, for instance, may aid the future development of new cultivars valuable either because of their improved properties or because of declines in yield in the current cultivars.

These intraspecific genetic values are not limited to agricultural species, however. There are, for example, genetic varients of a number of plants that are capable of surviving in areas with high concentrations of heavy metals (Bradshaw 1975). Even if the normal, non-metal-tolerant form of these species are neither deemed valuable nor endangered, the mutant form could be both. It exists in only a few locations, and is dependent on a specialized substrate which leaching and the plants' own activities will gradually eliminate. Yet such forms may allow us to more quickly stabilize and heal old mining sites, and thus could be of immense economic value. The genetic variant need not have such an immediate market value, either. For similar reasons, it may be valuable to preserve local populations of a species adapted to an unusual habitat or at the edge of its range due to the aesthetic value it has in that locale.

There may be indirect benefits to preserving genetic diversity within a species, even where no direct benefits (such

as those outlined above) can be enumerated. Here genetic diversity is a tool, an instrument for increasing the overall probability of a species' survival. There are several reasons to expect that a more genetically uniform population is at greater risk of extinction:

(a) Inbreeding in a population of genetically similar individuals generates a high degree of homozygosity, exposing deleterious recessive genes which would otherwise have had little or no impact on fitness. The result can be a marked reduction in viability and/or reproductive success, at least in the short term, while this "genetic load" is being weeded out (Templeton and Read 1983).

(b) The increased homozygosity of an inbred line can also cause permanent decreases in fitness, to the extent that heterosis (heterozygote advantages) is important in nature. Thus a heterozygote at a locus coding for some temperature dependent regulatory enzyme might be able to thrive at a wider array of temperatures than either homozygote.

(c) Genetic uniformity can make a population more vulnerable to environmental shocks. The variability of natural environments has been credited as one of the prime factors maintaining genetic diversity, shifting the relative fitness of various strains (Antonovics 1984). Thus a genetically uniform population which seems to thrive in a relatively unvarying environment in captivity, may nonetheless find itself much less capable of coping with adverse weather or a disease outbreak than a more diverse population.

(d) Genetic variability is the raw material from which evolutionary change is made. A genetically uniform population may be unable to adapt as conditions change in the long term, either due to natural factors or human intervention. Again, this could take the form of a climatic shift (whether due to advancing ice ages or deforestation) or a biological one (an introduced competitor or evolutionary change in a parasitic species).

The first two of these come under the general heading of "inbreeding depression," and have only recently begun to be teased apart (Frankel and Soulé 1981). While the overall phenomenon has been thoroughly documented, primarily due to its importance in crop and domestic animal breeding programs, the relative importance of its two component parts in various taxa remains a subject for further study. The differences between them could have profound implications for the optimal design of captive breeding systems.

The second pair of costs to genetic uniformity could be labled "short-" and "long-term adaptability" respectively, and have been the subject of very little research. Their importance in determining the viability of populations over time can, at present, only be guessed at.

CONCLUSIONS

It is clear from the preceding review that commercial, recreational, scientific, and ecological methods of valuing species do not yield identical or even similar rankings of living organisms. Species of high market value are not necessarily aesthetic, scientifically interesting, or ecologically important. The most valuable species aesthetically typically have no direct consumptive value. The species whose loss might most severely disrupt the functioning of ecological communities may be inconspicuous, evolutionarily routine, and of no direct market value. This fact is unlikely to be altered either by improved knowledge or changing societal values. Therefore, we can expect that there will be an ever present need to develop and use means of trading-off the priorities for species preservation as developed from these different perspectives.

Making such trade-offs is a matter for politicians and economists, not for biologists. Nonetheless, Biology can provide important inputs into the decision-making process. Imagine the policy maker faced with a list of all known species, with the task of picking "who shall live and who shall die." Such a list would be continually expanded by new discoveries of taxonomists. Any combination of species chosen from this list represents a different conservation option, but not all such options are really feasible. Ecologists, by illuminating species interactions, can help eliminate from consideration "pseudo-options," combinations of species which would not persist. Each of the remaining options could then, in theory, be assigned a price,

based in part on an understanding of the ecology of the species involved and what would be necessary to preserve them. It is important to note that individual species cannot be assigned such "conservation prices" independently because the cost of conserving one species often depends heavily on what else is being conserved. Finally, these costs would have to be weighed against the expected benefits that would accrue from such efforts. Here again, biological input might be crucial. Many of the values suggested for wild species derive from the possibility that they will be found useful in the future, whether for food, medicine, or industrial input, properties which ecological theory can help identify. These four types of input: (a) identifying species, (b) eliminating pseudo-options, (c) estimating conservation costs, and (d) predicting social value, will be discussed in greater detail below.

IDENTIFYING SPECIES. The task of identifying, describing, and determining evolutionary relationships among the living organisms of the world is far from complete. Estimates vary concerning the degree of completeness of the current record, but there is little doubt that many more species remain to be described, especially from tropical areas and among invertebrates. Increased efforts to complete the task of describing and identifying species are needed, especially since many species are otherwise destined to be exterminated before they are even described (NAS 1980). We cannot possibly think about valuing species of whose existence we are as yet unaware.

ELIMINATING PSEUDO-OPTIONS. Rational policies concerning the allocation of preservation efforts require information about the consequences of taking or not taking particular actions. Insights deriving from deletion sensitivity analysis, in the broad sense, can be used to identify real option sets. If we can determine the likely consequences on the remaining species in the system if a particular species is lost, the likely states of the systems after perturbations can be determined. Better knowledge of keystone species and where and why they are found, is necessary for achieving these goals.

Highly improbable states can be identified and eliminated from the set of real options available to societies through judicious application of biological knowledge. Components of ecological knowledge that can make important contributions to this process are life history theory, predator-prey theory, the theory of populations in patchy environments, and theories of nutrient cycling and energy flow.

ESTIMATING CONSERVATION COSTS. Perhaps the most important contribution biology can make to conservation decision-making is in outlining what it will take to conserve particular species or groups of them. The Minimum Viable Population (MVP) approach, pioneered by Soulé (1980) and much elaborated upon by Gilpin and Soulé (in press), attacks the problem from a single species perspective. The goal is to predict how large a population is needed for a species to persist, with a particular probability over a specified time period. MacArthur and Wilson's (1967) theory of island biogeography stimulated a more community

oriented approach, predicting the number of species that will naturally be maintained on habitat remnants of different sizes. The growing literature on extinction-proneness of species (e.g. Terborgh and Winter 1980, Gilpin and Soulé, in press) can help predict which species will be most likely to survive, and, conversely, which species will be most difficult (and, presumably, expensive) to retain.

In some cases, the most cost effective way to preserve a particular species set will involve more intensive management than has been suggested thus far. Ex situ preservation, while generally expensive on a per species basis, may be the most economical way to preserve particular extinction-prone species, especially ones with large habitat requirements or low natural population densities. Similarly, the possibility of managing natural areas for species supersaturation needs to be vigorously explored, as it may allow for the retention of much greater than natural biological diversity in habitat-based preservation systems. Basically, such a procedure would involve attempts to alter, in favorable directions, both extinction and colonization rates. The management costs of these efforts may turn out to be very modest.

PREDICTING SOCIAL VALUE. Scientific information cannot be used, by itself, to establish values. Nonetheless, given that we can recognize aspects of living organisms that have had value and, hence, are likely to have value in the future, scientific information can be used to help identify species and assemblages of species with features likely to give them societal value.

Some of these are quite obvious. For example, close relatives of currently used domesticated plants and animals are especially likely to have genes that can be incorporated into present and future organisms of commercial value. Taxa that have yielded commercially important species in the past may be especially likely to yield additional species of value in the future. Others, such as the prediction that medicinal plants can be identified by the use of plant-herbivore theories, are less obvious. Ecological knowledge may also be used to identify habitats and ecosystems containing species likely to have the desired properties. For example, understory plants of tropical wet forests are especially likely candidates for chemicals of medicinal value.

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Biological knowledge is, thus, likely to be of considerable value at all stages in the process of deciding where societal resources devoted to the preservation of species should be allocated. By providing information on the total range of species present on Earth that can potentially be preserved, by showing why only a subset of all mathematically possible species combinations are really ecologically feasible, by defining the requirements for preserving individual species and assemblages of species, and by developing new management techniques for both in situ and ex situ preservation, biologists provide information without which action plans are likely to be ineffective and

unnecessarily costly. Moreover, if biologists and decision-makers cooperate more extensively at all of the stages of decision-making, both the quality of the decisions and the relevance of future biological research to management objectives are likely to be increased.

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Critical Assessment of the Value of and Concern for the Maintenance of Biological Diversity

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Abstract

Many observers are concerned that the world is now in, or closely approaching, a period when an unprecedented number of habitats will be destroyed and species will become extinct. The main cause of this situation is that humans generally under-value biological diversity.

This essay examines how biological diversity is valued and by whom. A major difficulty is that much of the literature tends to exaggerate the value of biological diversity. Several issues are examined -- the loss of species, population growth and degradation of biotic systems, the fragility of the biota, and the pricelessness of biological diversity -- in an attempt to place the range of values which various individuals and groups attribute to biological diversity in perspective.

Some means of drawing all of these values together is needed if a set of policies to ensure that the biological diversity people value is indeed maintained. To formulate these policies requires a set of multidisciplinary procedures and activities since none of the many individuals and groups involved has a sufficiently compelling set of reasons for ensuring that effective programs for maintaining biological diversity will be implemented and sustained. I suggest how an information-theoretic model might be used to encourage this multidisciplinary interaction.

1. Introduction: Purpose and Approach

Many concerned observers estimate that a million species could be extinct by the year 2000 and that most of the world's tropical forests will disappear by the middle of the next century. They expect these losses because humans generally under-value biological diversity.

At present, there is little agreement on how to value biological diversity, who should value it, and what dimensions of it should be valued. Opinions about biological and economic values are so strongly merged with religious and philosophic concerns about the biota, its diversity, and the responsibility humans have for maintaining it, that a general approach to valuing biological diversity has eluded scholars and policymakers alike.

To compound the problem, no single group, whether ecologists, biologists, economists, or anthropologists, has proposed a set of reasons which are sufficiently compelling and appealing to generate the necessary support to ensure that all of the biological diversity they value will be maintained. Even within disciplines, people have difficulty reconciling the different values they hold, the criteria they believe are relevant, and the methods that should be used to maintain the biological resources they value.

Few of these differences in values can be resolved to everyone's satisfaction. Inevitably, if biological diversity is to be maintained, they will have to be mediated in a larger (public) forum. This will require: (i) a general analytical framework which enables the individuals and groups involved to combine their perspectives; and (ii) a set of procedures to encourage the individuals and groups to cooperate and compromise for the purpose of achieving their broader goals.

This essay examines these two issues. It begins by discussing the arguments about the predicted losses of species and habitats. This helps to identify how biological diversity has been valued and by whom. These data indicate the potential usefulness of a framework fo integrating the different perspectives of those who value biological diversity. The framework, which emphasizes the formal similarity between biological diversity and information, is general enough to encompass the major concerns of biological scientists (that biologica diversity is valuable genetic and ecological information) and social scientists (that information has financial, political and social cost of collection, evaluation, preservation and use which have to be weighed against expected benefits). But, to be used effectively, the framework has to be placed in a broader context. In particular, direct public involvement is required to ensure that those whose opinions are relevant for the maintenance of biological diversity are sought and that any actions which are beyond the capacities of isolated groups and individuals receive the appropriate public support. Public involvement is also needed to keep issues related to biological diversity in perspective because, despite how much some individuals of groups may value biological diversity, it is only one of many things that humans are concerned about.

The paper is arranged as follows. Section 2 considers how exaggeration and hyperbole influence our perceptions of the value of biological diversity. Section 3 examines some of the dimensions of value that humans apply to biological diversity and (implicitly) how they rank them. Since values have meaning only in particular contexts[1], I consider four common arguments: the loss of biological diversity; the impact of population growth on the integrity of biotic

systems; the fragility of the biota; and the pricelessness of biological diversity. Section 4 presents a framework for valuing biological diversity which focuses on its ecological and genetic information. It provides a basis for formulating a coherent set of policies to maintain biological diversity. Section 5 contains a summary and concluding observations.

2. Dealing with Exaggeration about Biological Diversity

Trying to place conservation issues in perspective is an unrewarding task. As Maass (1968:271) noted, conservation has "virtuous connotations" so that it is never easy to challenge the points its proponents make without appearing to be biologically reckless. Moreover, attempts at perspective risk criticism from both sides. For instance, some authors (Zuckerman 1973:139; and Frankel 1981:210-212) reject some conservation arguments as nonsense.[2] Yet, those who make the claims presumably believe that their position is reasonable representation of reality. The problem is one of context. What is overstated (or exaggerated, fanciful, or excessive) to one person can be reasonable (or moderate, plausible, or balanced) to another.[3] Still others may be indifferent.

Because the contexts in which statements are made and interpreted vary, communication is always a problem. One difficulty faced by those who believe that biological diversity is severely threatened is having the relevant policy-makers respond by, for example, providing material support for the preservation of biological diversity; and/or imposing restrictions on individuals and groups whose activities threaten the biota. Because of all the other issues policy-makers deal with, conservationists often find it difficult their concerns

known. A major problem is gaining attention. Given the gravity of the issues involved, understatement seems intellectually dishonest and unadorned statements run the risk of being swamped by the messages of other interest groups competing for the attention of policymakers. Hence, there is an in-built tendency to exaggerate (cf.McPherson 1983).[4] But, because exaggeration is more effective at gaining attention than sustaining support, those who habitually exaggerate face the prospect of having to increase the stridency of their message to maintain attention.

This strategy can backfire. An example is Ehrlich (1968) who wrote in The Population Bomb that (ibid.:xi):

> The battle to feed all of humanity is over. In the 1970's the world will undergo famines -- hundreds of millions of people are going to starve to death.

This statement (and the whole book) had a major impact on popular opinion. But the facts have been otherwise: hundreds of millions of people did not starve to death. Indeed, the 1970's will be remembered as the period when the Asian countries, where the majority of the world's poor live, significantly improved their aggregate food situation (Johnson 1980; Tacke 1983; Perkins and Yusuf 1984:Ch.3).

When such a dramatic prediction proves to be false, as also happened with the Paddock and Paddock (1967) projection of global famine in 1975, the credibility of those who make them suffers. Thus, for example, when Erhlich (cited in Breach 1981:480) stated that "the planetary life-support systems in which humanity is embedded are collapsing" or when he argued that (cf. Ehrlich 1980:68) "the only practical solutions to [humanity's] major problems are unrecognized or shunned by most practical people" observers have to wonder how much of the message is fact and how much is fancy.[5]

The dilemma is clear. Exaggeration can gain attention but it can undermine the communication process.[6] Moreover, communication can be undermined at a number of levels. As noted above, people who respond to a particular message will devalue its source when the (exaggerated) predictions prove to be false. At a second level, confidence in the scientific process in general and scientists in particular (whether they are natural or social scientists) is eroded when eminent individuals like Ehrlich and others cited below use their positions for ideological purposes. At best they have confused the distinction between scientific and unscientific opinions[7]; at worst, as Russell (1959:187) observed, they have used the "language of science for the purpose of making prejudice seem more respectable."

Confidence is eroded further when the general public and policy-makers come to recognize that natural and social scientists are just one more of the many pressure groups in society. They begin to realize that the adamance of many of the assertions scientist's make does not represent the words of someone who is dedicated to the "habit of truth," to borrow Bronowski's (1965:Ch.2) phrase, but those of an ideologue whose opinions can be heavily discounted or even ignored.[8]

The potential breakdown of communication, criticism from peers for unscientific analysis, and scepticism from policy-makers should impose limits on the extent to which people exaggerate about impending biological peril. But, the limits are rarely effective. As a result, many of the un-scientific arguments of prominent scientists have had a profound impact on the current debate. Their acceptance results from a combination of the loose way that the subject of maintaining biological diversity is defined; asymmetric information (most of the audience is unaware that the arguments are un-scientific); the

virtuous overtones of "conservation" (noted above); the indifference or preoccupation of those who could dispute the claims; and as Cooke (1956:11) put it, the effectiveness of the exaggeration in bullying the audience into sharing a prejudice.

The following quotes illustrate these points. Referring to the vital role of genetic resources, Wilkes (1977:10) stated:

> The [genetic] reservoirs are our irreplaceable genetic heritage which has assured freedom from want for every civilization that has ever existed.

Praising the fundamental good sense of small farmers Mooney (1980:6) asserted that "throughout history, every subsistent farmer has been an aggressive plant breeder." To emphasize that not enough attention was being given to the preservation of genetic resources, Walsh (1981:423) concluded:

> Meanwhile the voices crying in the wilderness are warning that the wilderness is fast disappearing.

Caufield (1982) dramatized her concern about the clearing of tropical forests for the production of export beef with the headline "Big Mac Devours the Jungle." Finally, Wolkomir (1983) highlighted the genetic vulnerability of species such as the elephant seal and the wild turkey with his essay "Draining the Gene Pool."

At this point a word of caution seems appropriate. The attempt to place exaggeration about biological diversity in perspective also has to be kept in perspective. All non-trivial statements about biological diversity have some degree of error and some ideological content. The error is the result of the physical limits of our perception and the costs of information. It is physically impossible for us to be fully informed about all relevant biophysical and social dimensions of maintaining biological diversity. Furthermore, because

of the opportunity costs of the resources needed to collect and interpret information it pays us to ignore some information even though we are physically capable of obtaining it.[9] Similarly, none of the statements can be free of ideology because the contexts in which they are made and interpreted differ for every individual. The choice of what to emphasize about a particular issue is influenced by the social aspirations and needs of those involved.

Again, there is a dilemma: since non-trivial statements about biological diversity cannot be error-free or devoid of ideology, the potential for exaggeration always exists. The analytical challenge is to seek some degree of balance. Using the above statements to illustrate, we can recognize that their adamance makes them unscientific assertions designed to reinforce existing prejudices rather than persuade by facts or logic. From my perspective, they overstate the threats to biological diversity. Wilkes' observation at odds with evidence on current world poverty, let alone any appeal to history (Myrdal 1970; Moore 1972; Ency.Britt. 1974,vol.7:498; Griffen and Khan 1978; Schultz 1980).[10] Mooney has a romantic view of the capacities and motivation of subsistence farmers (see also Mooney 1980:103). Throughout history, many subsistence farmers have never bred plants in any meaningful sense (cf.Sauer 1952; Hawkes 1983). Finally, Walsh's conclusion only makes sense if the efforts of international agencies, governments, private corporations, and individuals to maintain biological diversity are ignored (USDA 1981; Plucknett et al. 1983; Lyman 1984; Duvick 1984; Oldfield 1984:Ch.10).

Of course, many people will not share my perspective; indeed many will think that I have been exaggerating. Such differences of opinion are inevitable because so many individuals and groups are concerned

about maintaining biological diversity. These differences will not be resolved by having everyone see the world my way or someone else's way; they have to be addressed by dialogue and debate so that each of the groups involved share their respective concerns and come to understand those of others. This will require a degree of cooperation which so far has been lacking in efforts to maintain biological diversity. While achieving this cooperation will be difficult, as Schelling (1971) reminded us, it is not an unsolvable problem merely one that has not been solved. This issue is considered further in section 4.

3. Exaggerated Values of Biological Diversity

This section critically assesses four sets of arguments which tend to exaggerate the value of biological diversity: the loss of species and habitats; the pressure on biotic systems of human population growth; the fragility of the biota; and the pricelessness of biological diversity. The four topics are related as follows. It is widely believed that the world is experiencing the early stages of a "biological massacre" which will remove a million species from the Earth by the end of the century. Habitat modification associated with uncontrolled, or inadequately controlled, population growth is a major (if not the main) cause. This population pressure has led to environmental mismanagement which has forced many (fragile) biological processes to the point where the "web of life itself" is about to unravel. Efforts to reverse these trends have been inadequate because humans generally under-value their "priceless heritage" of genetic resources and biological diversity.

a. Loss of Biological Diversity.

There have been two themes in the literature. The first relates to the genetic erosion of crop germplasm; the second to the loss of species and the degradation of ecological communities.

Early statements about losses of crop germplasm lacked specificity. A National Academy of Sciences ad hoc Agricultural Research Policy Advisory Committee report (cited in Miller 1973:1232) noted:

> The genetic variability upon which man depends for future breeding programs is being eroded and lost almost everywhere in the world, and we are not taking adequate steps to salvage the material before it disappears.

Frankel (1974:56) made a similar point. The generalizations have persisted, as when Mooney (1980:15) argued that "...the world is losing hundreds of thousands of wild species, some of which are close relatives to cultivated varieties." Several others like Wilkes (1977:16), Brush, Carney and Huaman (1981:86), Brill (1981:215), Hawkes (1983:vi), and Chang (1984:252) have referred to the "alarming" rate of disappearance of crop germplasm in general and potato, wheat and rice germplasm in particular.

These generalizations are also evident in discussions about the loss of biological diversity. For instance, Lovejoy (1976:55) asserted:

> Predictions of extinction rates of 100 to 1000 times normal by the century's end, and of extinction of one-quarter or more of all species, no longer seem unrealistic.

However, over recent years estimates of the potential losses have been more concrete, with wide agreement on a figure of around a million species becoming extinct by the turn of the century. This estimate was

derived from Myers (1979:Ch.2; 1980:62; 1981; Dept. of State 1982:56) who noted (Myers 1981:141):

> ...the earth's stock of species is being depleted even more rapidly than several of its most precious mineral deposits. Of the planetary stock of 5-10 million, one species disappears each day. By the end of the 1980's, the figure could be as high as one an hour. By the year 2000, 1 million species could be extinct, and the rate of depletion could continue to grow.

Myers developed these estimates in The Sinking Ark which drew on a study of the rates of conversion/destruction of tropical forests (NRC 1980). This report, which projected that all of the world's tropical forest will be "gone by the middle of the next century," had a major impact on subsequent studies of species and habitat loss (NRC 1980a:33; Dept. of State 1982:55-56; Oldfield 1984:285).

This estimate of the one million or so species that will disappear is now an institutional constant. Eckholm (1978:5) based his projection of the impending "biological massacre" on it. The Council of Environmental Quality emphasized it in a report on biological diversity (CEQ 1980:31); it has been widely cited, for instance, in NRC (1980a:43), the Strategy Conference on Biological Diversity (Dept. of State 1982), Fisher (1981:1), Harrington and Fisher (1982:125), Holden (1982:1214), Oldfield (1984:285), Wilson (1984:121-122), and O'Brien et al. (1985:1428); and, finally, it has been the subject of editorial comment (New York Times 22 March 1982; The Economist July 1984).

As a final example, it is useful to cite Oldfield (1984) who placed these losses in a broader context. She observed (ibid.:vi):

> ...the fate and survival of nations, and possibly the welfare of the entire human species, will probably be decided by the present generation within the coming decades: if the

> energy crisis does not destroy the backbone of modern industrialized economies, the impending genetic crisis eventually will. The symptoms of such a crisis are already upon us: the massive losses of crop and livestock gene resources, accelerating rates of species extinctions, and the progressive conversion of valuable natural genetic reservoirs to more short-term economic uses.[11]

While there are numerous ways to evaluate the above arguments, I shall consider three: are the losses projected a serious representation of some future reality?; is their statistical base reasonable; and do these disaster scenarios serve particular ideological purposes?

These arguments cannot, in my view, be taken literally. There seems no doubt that, just as in the past, some species will become extinct and some habitats will become irreparably modified by the tu of the century. But, an acceleration in extinction at the rate implied by the above examples is not supported by the evidence. First, none of the above sources has identified the individual speci that have allegedly disappeared at the rate of one a day and are likely to disappear at the rate of one an hour. Such data do not exist because the estimates were derived from macro trends and not field-level observations. Indeed, recent data on species loss shows that the estimate that one species is being lost each day is grossly overstated. For instance, only 63 species of plants were added to the endangered species list during the first nine years the Endangered Species Act of 1973 was in force (Elias 1983:20). Similarly, the listings provided in the International Union for the Conservation of Nature and Natural Resources (IUCN) Red Books show that this estimate is exaggerated (cf.CEQ 1980:59-60; Wolf 1985:142-144). Second, there is no evidence to show that extinction is accelerating at anything

like the rate needed for one million or so species to disappear by th turn of the century (Tierney 1985:57-58).

Third, none of the data provided in recent assessments of the state of crop germplasm (Plucknett et.al 1983; Hawkes 1983; Duvick 1984; Lyman 1984; and Oldfield 1984) supports Mooney's argument that the world is currently losing hundreds of thousands of wild relatives of crop plants. Moreover, despite repeating the point several times, Oldfield (1984) did not give any data to show that "massive genetic losses" are "now taking place" (ibid.:289). Her evidence consisted o anecdotes about difficulties collectors have had locating pea, cocoa, alfalfa, pear and other species (ibid.:279) and a review of the threatened and extinct species. Her Chapter 9, which deals with extinction, mentions 129 species. Given the widely cited estimate of 5-10 million species on Earth, this is not a "massive genetic loss" i any sense that I find meaningful.[12]

Part of the reason that the arguments cannot be taken literally i that their statistical base is weak. As noted earlier, Myers derived the estimate that one million or more species will disappear by the end of the century. A review of his work (Myers 1979:Ch.2) shows tha the estimate is based on several guesses, the principal one of which is the rate of destruction of tropical forests. (The same methodolog was used to derive similar estimates of species loss for the Global 2000 report cf.Wolf 1985:128.) Lugo and Brown (1982) have shown that Myers has over-stated this variable by a wide margin. Recent satellite imaging provides further support (cf. Economist 4 Sept. 1984:87). Furthermore, in their study of global deforestation, Woodwell et al.(1983) treated Myers' data as extreme values.[13] Other problems with the estimates are: (i) that Myers like the National

Resource Council study treated forest conversion as forest destruction (cf.Myers 1979:119-127;Ch.11; NRC 1980:29-33); and (ii) he assumed that all tropical forest has the same potential for conversion and/or destruction. The latter overlooks the many bio-physical and ecological contraints such as toxic soils and tse-tse fly infestation which will continue to make large areas of tropical forests physically and economically uninhabitable (cf. Ormerod 1976; Sanchez et al. 1982).

The weakness of these estimates is also illustrated in other ways. To illustrate, as Tierney (1985:57) noted, now that it is obvious that the rate of species loss is nowhere near what has been predicted, attention is being deflected by the argument that the losses are occurring among the species we do not know about. This view, which is common (cf.Ehrenfeld 1976:650; NRC 1980:30; CEQ 1980:31; and Wilkes 1983:135), was popularized by Lovejoy (1976:54) when he asserted:

> Species are becoming extinct today before they are becoming known to Man. Usually we remain in eternal ignorance of what we have lost.

The logic of this view eludes me: by definition, we do not know we have lost something we do not know about; we may guess that it is the case, but as a matter of logic we can never verify or refute it.

Few people deny that tropical forests are being cut over and in some cases destroyed (Smith 1981; Williams 1985). For example, the 1983 fire in Indonesia destroyed about 30 thousand square kilometers of forest, woodlands, and peat swamps (cf.Wolf 1985:129). And, one of the last vestiges of Hawaiian rainforest is being cut as fuel for electricity generation (Holden 1985:1073-4). However, in my view, we should be circumspect about accepting at face value the predictions of those who treat forest conversion as destruction; who under-state the

resiliency of tropical biomes (discussed in section 3d below); who revive the canard about the ecological destructiveness of slash-and-burn cultivation (cf.Myers 1979:167-169; and Nations and Komer 1982:8); and who assert that we have lost something we do not know about.

The widespread appeal of the arguments about the loss of species and habitats, despite their weaknesses, raises the issue of whose interests do the arguments serve. It is difficult to rationalize the frequently made claim (cf.Woodwell 1974; Dixon 1976; Lovejoy 1976; Eckholm 1978; Blair 1983; Hawkes 1983; Oldfield 1984) that the major concern about maintaining biological diversity (or aspects of it) is in the interest of all humanity. This claim is characteristic of what Scott (1968:280) called the "special conservationist approach" t resource issues which holds that "...nature must be protected from man's ruthlessness, wastefulness, and ignorance...". It serves the purpose of setting conservationists apart as having a special knowledge and a set of goals which are more worthy than those of the rest of humanity.[14] It also demonstrates a particularly cynical vie of mankind's ability to respond through social action to conservation issues. Furthermore, the view reflects a special insensitivity to the problems of poor people who depend on tropical biomes and other areas of biological diversity that conservationists (who typically gain their livelihood elsewhere) want to save.

The goal of maintaining biological diversity for the welfare of humanity serves the additional ideological purpose of diverting attention from the immediate needs of particular groups such as the poor (cf. Zuckerman 1973:130). Relative to the "welfare of humanity," the day-to-day concerns of the poor who depend on the resources of

tropical forests are easy to ignore! Furthermore, despite the attempt by Meadows et al. (1973), Myers (1979:120) and Ehrlich and Ehrlich (1983) to equate higher levels of income with increased environmental pressure, there is strong evidence that poverty and stagnation are two of the major threats to the environment. Krutilla (1967), Maass (1968), Zuckerman (1973), Pryde (1983) and others have pointed out that rising levels of income improve attitudes towards conservation. As carefully noted by a World Bank report, persistent poverty does not (cf.World Bank 1979:7).

For those concerned with maintaining biological diversity, a priority should be the alleviation of poverty. With few exceptions (cf.Eckholm 1978; Myers 1979,Ch.20), the literature cited above has ignored this issue.

b. Population Growth and Biological Diversity

There is an argument in the literature which is simple, understandable, durable, but distorted. An example is the following (Borlaug 1983:692):

> The challenge just to maintain already inadequate per capita food consumption is awesome. It took roughly from 12000 B.C. until about 1850 for world population to reach 1 billion, only 80 years to reach 2 billion, and only 45 years to reach 4 billion. We are now faced with the need to double food production again by the first decades of the 21st century.

The argument derives intellectual support in the notion of a "food-population" race first popularized by Thomas Malthus (Malthus 1798 in Fogarty 1958:5-11) and widely repeated and extended (cf.de Castro 1952:4; Dumont 1957:531-3; Harrar 1964:2; Ehrlich and Ehrlich 1970,Ch.1; 1983:11-13; Poleman 1977; Borlaug, Sprague and Anderson 1980 and Brown 1985:201). In an extreme form, it is the "triage"

approach to the food issue (Paddock and Paddock 1964:222; Hardin 1974 in which entire countries have been classed as "can't be saved." The basic idea is that population pressure undermines the resource base and thereby reduces the standard of living of subsequent generations (cf.Hardin 1974:565). Sometimes the two arguments are combined: population is going to double therefore the food supply has to be doubled but the increase in population will lead to a dramatic reduction in biological diversity (which, to complete the circle, wil compound the difficulties of increasing the food supply).[13]

Other versions of this link between population growth, food production, and environmental pressure have appeared (Bundy 1960:362-367; Brown 1965:vi-viii; Revelle 1968:3; Rockefeller Foundation 1975:1; Wilkes 1977:317;1983:133; Gilligan 1978:A13; NBPGR 1979:5; Brandt Report 1980:105-6; NRC 1980:32; Dept. of State 1982:12 Rachie 1981:53; and Kahn 1985:191-194).[14]

This argument has two deficiencies: (i) it deals only with the dynamics of food demand; and (ii) it ignores the basic dimensions the food problems facing most poor countries. Its focus on food demand results from the implicit assumption that population growth is exogenous, i.e. the population will continue to increase rapidly despite changes in the supply of food or any social changes which may occur. This assumption seems so deeply embedded in conventional thinking that few people question it. Others, like Ehrlich and Ehrlich (1983:11), presume that the population will have to continue growing rapidly because the alternative, which they imagine to be "horrendous disaster," cannot be "humanely" contemplated. Ironically, Malthus, from whom the this basic mind-set has been derived, did not treat population as exogenous. For him, population growth depended or

the level of subsistence (which neo-Malthusians cite as they focus on the world's "dwindling" resources) but that the level of subsistence was socially determined (which neo-Malthusians tend to ignore). Indeed, Volume II of Malthus' Essay on Population is primarily a demonstration that the link between population and subsistence is culturally determined.[17]

Much evidence exists to reject the idea that population is exogenous (cf.de Castro 1952; Bennett 1954; Deevey 1954,1974; Leibenstein 1957,Ch.10; Taeuber 1963:41-45; Pyke 1964; Miro 1973; Dubos 1973; Scrimshaw 1978; Eberstadt 1980; Cohen, Malpass and Klein 1980; World Bank 1984:56-78,Ch.9; and Brown 1985:206-8). Without ignoring the negative aspects of high population growth, these studies show that variations in population growth rates across countries depend in large part on differences in public policy and parent's responses to changing economic and social circumstances. This is illustrated in numerous ways. Until recently, most Governments in Sub-Saharan Africa, which is the only area of the world where population growth rates increased during the 1970's, most Governments had pro-natalist policies. These policies persisted despite the general decline in the per capita food supply and the negative effects population growth was having on Government-sponsored development efforts (cf. World Bank 1981,1984; Eicher 1982; ODI 1983; Sai 1984). In other countries, most notably India, China and Indonesia (cf. World Bank 1984; Perkins and Yusuf 1984:204-5; Nag 1985; and Brown 1985:203-6), population growth rates have fallen sharply over the last decade. There are many reasons for the decline: government pressure; high rates of urbanization; improvement in the status of women; expanded education; increased economic opportunities; and rural

development (World Bank 1984; Burns 1985; Vining 1985). This evidenc reaffirms the importance of social policy and social circumstances as determinants of population growth.[18]

Few people would deny that the "unchecked" expansion of populatic will inevitably undermine the integrity of ecosystems and seriously reduce biological diversity (Ehrlich and Ehrlich 1970:3; 1983:11-12; Peccei 1973). However, the point of contention is whether population growth is in an meaningful sense "unchecked." Population densities are certainly high in some areas of the world (Rwanda, Egypt, Bangladesh, and Java) and some irreparable ecological damage has occurred, but the environmental damage attributable directly to population growth has been less severe than some observers have suggested. An important development over the past decade has been th increase in grass-roots agitation for the preservation of biological diversity in both rich and poor countries (cf.Wright 1982; Barnard 1982; Iker 1983; Harrison 1983; Hand 1984; Omvedt 1984; Nevin 1985). When added to the international attention to population and environmental issues, especially since the Stockholm Conference of 1972, these developments represent significant progress (Strong 1973; Pryde 1983; Clausen 1984.)

Perhaps the weakest aspect of the demand-side link between food, population and environment is that its obverse, a supply-side approach, trivializes both the food and the environmental problems. Because no biological entity, humans included, can reproduce without minimum level of food, space, light, and moisture, we can use supply-side logic to argue that if the world's population doubles (or whatever) over the next 35 to 40 years both the food supply and the capacity of the environment will have been adequate. This argument,

given its premises, is as sound as the demand-side approach. It, too, is distorted.

The error in choosing one approach over the other is that the links among population, food and the environment depend dynamically on both demand and supply factors. These, in turn, are determined by the biophysical and biosocial factors which influence the behavior of each segment of the population.

The second problem with the "food-population race" argument is that it does not represent the food problems poor countries experience. Since the mid-1970's, there has been a shift in emphasis in discussions of food issues. Formerly, the predominant "food problem" of poor countries was seen as an inadequate food supply (Dumont 1957; Harrar 1967; Revelle 1968,1974; Ency.Britt. 1974, vol.7:498-504). The solution was seen to be higher food production mainly through the expansion of irrigation; the increased use of high-response varieties of crops and improved breeds of livestock; improved crop protection and livestock husbandry; the greater use of fertilizers, mechanization, and herbicides and insecticides; and more effective resource management (cf.Johnston 1970; McDowell 1972; Mosher and Hill 1976). However, research since the "food crisis" of 1972-73 and the 1974 World Food Conference has provided new perspectives: (i) there are many food problems -- global, national, regional, village, and household; (ii) the distribution of food is frequently more important than the aggregate food supply; (iii) improving the distribution of food requires the alleviation of poverty as well as methods for modifying seasonal shortages and intra-family food deprivation; (iv) for the foreseeable future, the principal way of reducing poverty will be to expand employment opportunities in

agriculture and the rural areas; and (v) ensuring that the bio-physical capacity of the environment is sustained or, if possible, enhanced is a basic requirement of any program of agricultural and rural development (cf.Reutlinger 1977; Swaminathan 1977; Moore Lappe and Collins 1979; Williams 1981; Carloni 1981; Posner and McPherson 1982; Timmer, Falcon and Pearson 1983; Lele and Candler 1984; Mellor and Johnston 1984; and Mann and McPherson 1985,Ch.2). This shift in emphasis has meant that the maintenance of biological diversity is now an integral part of efforts to deal with the food problems of poor countries.[17]

To conclude this section, two points are worth noting. First, many people have argued that the world's population will double in the near future undermining the biological processes which sustain human life. This argument ignores the many social restrictions on population growth rate. Moreover, the projected ecological destruction is based on the assumption that social institutions and human behavior will not change. Human experience provides no basis for this view. Second, the persistence of the view that humans are engaged in food-population race rests on the idea that the principal dimension of the world food problem is aggregate food production. While this can be a problem (particularly in physically isolated areas), in most settings methods to enhance food security, improve the distribution of food, increase the productive potential of agriculture in "secondary" areas, alleviate poverty, and support research on ways to improve the incentives (or reduce the disincentives) for food and agricultural production at the local and regional levels are frequently more important.

c. Fragility of the Biota

The value of biological diversity has also been exaggerated by the emphasis given to its fragility; correspondingly less attention has been devoted to the range of the biological diversity in existence and its resilience. The fragility of the biota has been highlighted in at least three ways: human activities are critically disrupting the "web of life"; the biota and the Earth's life-support systems are collapsing; and "genetic disasters" such as the Irish potato famine and Southern corn blight in the United States show how sensitive biotic systems are to human interference.

The idea that human activities are life-threatening was central to the Club of Rome's work on the limits to growth in the early 1970's. For instance, Mesarovic and Pestel (1974:13) asserted that "species not perceived to be in the service of man have been systematically reduced in number or eliminated." On the same point, Woodwell (1974:84) observed that human intervention undermined the capacity of biotic systems to "repair" themselves. He urged that the pressure on these systems should be reduced because the thresholds at which they would unravel were not easily measurable (ibid.:86). Eckholm (1978:18) made a similar point.[20]

The Earth's life-support systems are "collapsing" (or are on the verge of collapse) for several reasons. Peccei (1973:165) suggested that ecological collapse was likely with the new "wave" of population expansion over the next several decades. Others have used an argument, widely attributed to Raven (cf.Mooney 1980:12; Norton 1985:20), that the loss of one species can take from 10-30 dependent species with it (cf.Eckholm 1978:18; Ehrlich and Ehrlich 1970:Ch.1; 1983:14). The idea can also be derived from the notion that

"cornerstone" or "dominant" species maintain the integrity of a particular ecosystem (cf. Ricklefs 1979:709ff; CEQ 1980:33-34,55; Anderson 1981:88-92; Harrington and Fisher 1982:7). Elimination of the species causes the ecosystem to unravel.

For several authors, such as Lovejoy (1976:55), Wilkes (1983:173) Oldfield (quoted earlier) and Brown (1985:205), the main threat is social collapse because the Earth has been losing the species upon which humans depend. Lovejoy found it to be ironical that humans so easily lost useful species but had difficulty eliminating pests. For him, "the planet is becoming increasingly a weed patch." Wilkes and Oldfield argued that the erosion of crop germplasm raised the prospec of agricultural collapse. This point was made even more strongly by Bass, the Director of the National Seed Storage Laboratory, who told Harley (1981:83) that "one variety preserved now may save an entire agricultural industry."

The final example of biotic fragility comes from Frankel and Soul (1983) who concluded that species which have suffered any human interference are particularly delicate. Their work on breeding programs designed to ensure that species were maintained (ibid.:71):

> ...reinforce(d) [their] suspicion that <u>any</u> loss of genetic variability whether due to natural causes (small population size, bottlenecks, directional selection) or to artificial inbreeding, is going to reduce the chances of survival in the wild. (Emphasis in original)[21]

Information on genetic disasters is widely available. Two themes are that species have become extinct and ecosystems have been changed beyond physical redemption. The demise of St. Stephen's wren, Stellar's sea cow, the Moa bird, the Madagascar elephant bird, the dodo, the heath hen, the woolly mammoth, various species of

rhinoceros, the passenger pigeon, giant land tortoises, and tropical forests have been well documented (cf.Bachmura 1971; Ricklefs 1979:Ch.35; Myers 1979; CEQ 1980; NRC 1980; Wolkomir 1983; Oldfield 1984:Ch.9; Tierney 1985). There is now reliable documentation of the approximately 53 species of birds, 77 mammals, and several hundred species of higher plants that have become extinct over the last two hundred years (cf.Jenkins and Ayensu 1975:93; Ricklefs 1979:Ch.35; Myers 1979:30-31; CEQ 1980:31; Frankel and Soule 1981:Ch.2; Elias 1983; and Wolf 1985:126). Genetic disasters in agriculture have been given special attention. The most frequently mentioned are the Irish potato famine (1840's), coffee rust in Ceylon (1870), wheat rust in the U.S. and Canada (1916), rice fungus in Bengal (1942), stem rust of wheat in U.S. (1953-54), tungro virus infestation of rice in India (1969), Southern corn blight in the U.S. (1970), wheat rust in Russia (1972), brown plant hopper in South-East Asia (1973), and recently fungal diseases of sorghum and mealy-bug attack of cassava in Africa (Miller 1973; NBPGR 1978; GAO 1981; Harrington and Fisher 1982; Wilkes 1983; Plucknett et al. 1983; Scheffer and Livingston 1984; Chang 1984; Oldfield 1984; and Kahn 1985).

The above arguments highlight two points: using their technology, humans have been able to interfere with biotic processes to such a degree that the Earth's ecological thresholds are rapidly being approached[22]; and, past genetic disasters are harbingers of potential catastrophes in the future. Overall, this literature predicts a shaky biological future.

However, while the challenge of maintaining biological diversity should not be underestimated, much of the evidence cited above can be viewed less negatively than so far has been the case. Four positive

aspects are worth mentioning. First, though some species have become extinct through human abuse and misuse of the biota, the number has been small because biotic processes are resilient and relatively stable. Second, while the genetic disasters have had severe local consequences, their global impact has been reduced through improvements in our understanding of the processes involved; the addition of scientific facilities for dealing with the problems; the expansion of physical infrastructure such as transport, storage, and communications to offset their effects; and international cooperation to increase our awareness of the measures needed to minimize their recurrence. Third, humans have already made major social adjustments to prevent the unnecessary loss of species and habitats. This is evident in the increase in preservation activity, laws and conventions, and other activities (such as the study of which this paper is a part). These efforts are likely to be intensified in the future. Fourth, there is such an wide array of biological diversity in the world and the processes which sustain it are sufficiently robust that the loss of species and the modification of ecosystems has not been (and for the foreseeable future) will not be a threat to human life.[23]

While this literature on biological fragility makes the valid point that biotic systems should not be exposed to persistent abuse, is it also important not to ignore (or discount) the enormity of the existing biological diversity and its resilience. (Indeed, were species and biotic systems as fragile as the literature cited above implies, perhaps the million or more species that observers predict will become extinct over the next decades would have already disappeared.) For better or worse, the immensity and resilience of

biological diversity are reasons why humans generally tend to undervalue the biota. Put bluntly, the biota is so diverse and most dimensions of it are hardy enough to withstand human abuse.

An important question is whether the latter situation will persist. The prospect that it will not is what worries those who emphasize the fragility of biotic systems. But, their arguments are considerably weakened by the way they fail to deal with the immensity of biological diversity. This omission is unfortunate because this same literature makes the point in several ways: ecologists and others note that there are perhaps millions of species that we do not know about (Lovejoy 1976:54; Myers 1979:16-18; NRC 1980:35-37; Oldfield 1984:285); moreover, despite all the activity by taxonomists over the last two centuries there are millions of species yet to classify (Dept. of State 1982:55-58; Wolf 1985:127-8); though the economic and biomedical rewards are high, perhaps only 1 percent of the tropical species have been screened for useful products (Myers 1979:81; Blair 1983; Oldfield 1984:95); and despite all of the concern about genetic vulnerability of crop plants, the major plant breeders have systematically screened only about 5 percent of the potential variability available (Wilkes 1977:10; 1983:134; NBPGR 1978:9; Dept. of State 1982:15; Duvick 1984).[24]

When we go beyond this literature and draw on work in population and molecular genetics, and plant and animal breeding, three points become clear: (i) the range of biological diversity is large; (ii) plant and animal breeders, micro-biologists, molecular geneticists and others continue to create genetic and biological diversity; (iii) a major constraint to their activities is not the paucity of the material with which they are operating but its abundance.

Evidence of the diversity of both individual species and ecosystems is widely available. Brewbaker (1964:2) described biological variation as being "immense"; Clarke (1975:56) noted that natural populations are "extremely diverse"; Stebbins (1977:16) argues that the gene pool of a population (which he defined as the sum total of different alleles) inherently has an infinite number of genetic combinations; Gould (1980:39) suggested that nature displays what he termed "boundless" though not "limitless" diversity; and McDonald (1983:81-85) who reviewed evidence of "naturally occurring genetic variation" cited Selander's (1976) conclusion that there is "an ungodly amount" of variation in existence. To give an idea of the potential magnitudes involved, Stebbins noted that the human genome has approximately thirty thousand gene loci of which approximately 2010 are heterogeneous. Thus an individual has the genetic potential to produce 2^{2010} (or 10^{605}) different gametes. By most standards, this is a large number.[23]

Further evidence of the range of diversity in plants was given by Allard (cf.Ency.Britt.1974,vol.14:496) who noted:

> One of the major facts that has emerged during the short history of scientific breeding is that an enormous wealth of genetic variability exists in the plants of the world and that only a start has been made in tapping its potential.[24]

Examples of this "wealth" of genetic variability are easy to find. At the level of the variety, Stebbins (1977:Ch.2) reported that 50 generations of selection for two traits (protein and oil) had not exhausted the genetic variability in a single variety of corn. At the level of the species, Epstein and Norlyn (1977) examined the salt tolerance of 7200 varieties of barley and found 22 which had the genetic plasticity to produce while being irrigated with sea water.

At a higher level still, Brush (1980:162) pointed out that:

> Eight different species of potato and as many as six thousand distinct varieties are cultivated in the Central Andes. Individual farmers may cultivate six or seven potato species and up to 35 distinct varieties. In a single village, it is possible to locate 75 named varieties. Comparable diversity has been found among the landraces of maize cultivated in the area.

The biological richness of ecosystems has been illustrated in several ways. The work of Darwin, Banks, de Candolle, Vavilov, (H) Harlan, Mayr, Dobzhansky, Mangelsdorf, (J) Harlan and others has provided many insights into the complexity and integrity of ecosystems from all parts of the Earth. The species richness of selected biomes has been well documented (cf.Myers 1979:22-23; CEQ 1980:53-54; Minckley and Clark 1981; Wilson 1985). The diversity of previously unexplored areas such as the isolated plateaus of Venezuela (Jackson 1985) and the geothermal rises (cf. Jannasch and Mottl 1985; Grassle 1985) is only now being examined systematically. Finally, the increasing attention to environmental concerns over the last two decades has led to a wider understanding and appreciation of the structure of ecosystems and how different species function in them. This work shows that most biotic systems are not only diverse but stable and resilient as well (cf.Isaacs 1969; Ency.Britt.1974,vol.6:281-5; Ehrlich, Ehrlich and Holdren 1977; Ricklefs 1979; Dubos 1980; Anderson 1981; McMahon and Bonner 1983).

The ability of humans to create genetic and biological diversity is evident in the history of plant and animal domestication. For instance, Frankel (1981:197) noted that the geographical spread of crop species had generated a "vast storehouse of genetic diversity." And, Hawkes (1983:47) asserted:

> The evolution of crop plants under domestication has given rise to more diversity, and of a more complex nature, than can be seen in any comparable set of wild plants.

Geneticists and breeders continue to create genetic diversity through a variety of techniques. Brewbaker (1964:Ch.6), Swaminathan (1970) and Hawkes (1983:22-25) stressed the importance of polyploidy in broadening the genetic base of crop plants. Harlan (1976:63;1983) noted the potential gains from hybridization of cultivated with related weed species. These have become relatively common particularly as sources of disease resistance in rice and potato (cf.IRRI 1980; Rutger, Webster and Figoni 1983; Brown et al. 1984:4; Chang 1984:254). Harlan's (1976) suggestion that selected inter-generic crosses could be useful sources of diversity has been confirmed by molecular biologists and genetic engineers (cf.Flavell 1981; Swaminathan 1982; Abelson 1983; Sondahl, Sharp and Evans 1984).

But, even at the level of a single species, breeders and molecular geneticists have found that the genetic variability is frequently larger than they had anticipated. For example, based on the study of somoclonal variability (i.e. variability among plants regenerated from callus), Scowcroft (1981:184) observed that "tissue culture *per se* is an unexpectedly rich and novel source of genetic variability." Characteristics of this diversity were described by Shepard (1981). Recent work on the activation of dormant genes in specialized cells using molecular techniques (DiBerardino, Hoffner and Etkin 1984) provides scientists with the potential to systematically unlock and screen some of the latent genetic characteristics which are no longer expressed in modern cultivars.[27]

Though this ability of humans to create genetic diversity is

widely recognized, some observers suggest that the diversity created is potentially harmful (to wit, the continuing debate over recombinant DNA technology) or that, at best, only relatively minor changes in selected genomes are possible (cf.Myers 1979:30; Kolata 1985; Brill 1985; Science12 July 1985:111-117). Perhaps the best reminder of the limitations of human skills is Marine's (1969:80) assertion that "you can't recreate an ecosystem." Though his reasoning was correct, namely that we can never know whether we have succeeded or not, as Dubos (1980:32-48) pointed out the capacity for recovery of ecosystems destroyed through natural or man-made disasters indicates a remarkable degree of ecological stability. Recent historical analyses are making the same point (Lewin 1985).

Perhaps the most significant development for the maintenance of biological diversity over recent times has been the rapid progress in molecular genetics. One consequence of this work is that the barrier to the transfer of genetic material across species, genera and even kingdoms are less restrictive than were once imagined (Lewin 1981; Marx 1982; Swaminathan 1984; Economist 6 April 1985:83-84). However, another consequence is that it has reconfirmed just how difficult some genetic problems are. For example, Leder (1982) described the large potential antibody diversity of which humans are capable. Yet, there is evidence that trypanosomes and malaria parasites (to name just two) have the capacity to change their surface configurations in ways which avoid the immune systems of their hosts (Kolata 1984; Godson 1985; Sharma et al. 1985; Donelson and Turner 1985). It appears that no matter how successful geneticists are, the problems of shifting patterns of resistance and new biotypes will be a constant challenge.

A major constraint on the genetic improvement of species is the limited ability breeders and geneticists have to screen for the few useful genetic combinations which emerge during any breeding effort (Neeley et al.1979:267). This constraint can be illustrated by an example given by Allard (Ency.Britt. 1974,vol.14:498) in which he noted that if two wheat varieties that differ by only 21 genes are crossed, the second generation would have around 10 billion distinct genotypes. This would require over 50 million hectares (roughly the area annually planted to feed grain in the U.S.) to grow every genotype at its expected frequency. Moreover, to store a sample of each of these genotypes, allowing roughly a litre per accession (cf.CGIAR 1976:4), would require 10 million cubic meters. (Total grain storage capacity in the U.S. is about 700 million cubic meters. The advantage of molecular and cellular level techniques is that they dramatically reduce the space required for obtaining a sample of the potential genotypes. As Scowcroft (1981:180) noted, to screen 500 thousand progenies from a single cross of a cereal crop would require slightly more than half a hectare. Using cellular techniques, the same number of cells can be accommodated in 50 ml. of a suspension culture.

But, even though these techniques save space they simply push the need for selection criteria to another level. Moving from the field to the tissue disk does not change the need for selection, it simply changes the nature of the selection process. This highlights a problem noted by Brewbaker (1964:145) who observed that the difficulty breeders face is not what genetic material can be discarded but what should be saved. With respect to the objective of maintaining biological diversity, this situation is ironical. To succeed,

breeders have to discard most of the genetic material they generate. Curiously, this is not an issue to which conservationists have paid much attention. Yet, the question that Jenkins and Ayensu (1975:96) raised about the unique "genetic quirks" possessed by rare species could also be asked of plant and animal breeders, namely what unique genetic quirks do they also discard through their selection procedures.

However, to ask this question simply confirms the point that the process of increasing or maintaining biological diversity inevitably involves some selection. In the process, genetic material will be discarded that, if we had better information and more physical and financial resources, we would not want to discard. This dilemma highlights the impracticality of existence value as a criterion for maintaining biological diversity (Marine 1969:33; Jenkins and Ayensu 1975:94; Ehrenfeld 1976:654; CEQ 1980:38-30).

d. Pricelessness of Biological Diversity

Several studies have suggested that various dimensions of biological diversity are priceless. For instance, missions from the National Academy of Science and The Rockefeller Foundation to China (Wortman 1974:5; Rockefeller Foundation 1980:7) referred to the country's "priceless heritage of indigenous germplasm"; Eckholm (1978) noted that, with respect to biological resources, "what is irreplaceable is in some sense priceless"[28]; and Oldfield (1984:267) argued that genetic resources are price-less but not valueless. As she explained:

> A resource, e.g., pure air or water or a gene resource, may have some value to an economy or a society; however it will not be considered economically important unless it has acquired a monetary price within the marketplace. A gene resource cannot be priced until it is

> considered scarce and some level of competitive bidding has evolved to determine its use, and until some method or technique has been developed whereby it (or its products) can be properly fitted into the production process. For this reason, a genetic resource is considered a "free good" until it has become scarce in an economic sense. This means that even though it may not be valueless, it is price-less.

Some people have implied that germplasm is priceless. For instance, Hawkes (1971) argued that "reservoirs of variability of our cultivated plants must at all cost be preserved." And others, who have described the biota as "invaluable"; or as an "irreplaceable resource"; or as mankind's "single most important resource" (cf.Cantlon, and Darnell cited in Marine 1969:34,81; Woodwell 1974:81; Wilkes 1977:10; Brush, Carney and Huaman 1981:16; and Chang 1984:255), suggest that its price is in a sense beyond measure.

These examples have at least four interpretations: the values are exaggerated; the term "priceless" is a convenient figure of speech; those involved may be unable to value the biological resources; or the resource or aspect of biological diversity does not have an assigned price.[29]

Perhaps none of those cited above thought they were exaggerating, yet some licence has been taken. For instance, is the phrase "at all cost" to be taken literally?; is every dimension of genetic diversity in fact "irreplaceable"?; and are humans obliged to treat all aspects of biological impoverishment as the loss of something priceless just because it is irreplaceable? On the last point, who for example apart from a small number of research scientists (cf.Dixon 1976; Razzell 1976) would seriously regret our biological impoverishment if we were indeed able to eliminate the smallpox virus (cf.Goodfield 1985)?

If the term "priceless" is used as a convenient figure of speech,

then those cited above would not have expected to have been taken literally. They would have expected their audience to keep their statements in context.[30] Unfortunately, this can result in major distortions. A useful illustration is the estimate of the million species that will disappear by the end of century. Some people have interpreted it as a shorthand way of dramatizing the problem of species loss; for others it is as a scientific fact.

The third reason why biological diversity has been described as priceless is that it is difficult to assign a value to it. This difficulty has two dimensions: some people value biological diversity so highly that they are not prepared to assign a nominal value to it; and biological resources are "open access" or "public goods."

It is a curious feature of every day experience that while some people have problems valuing biological resources, many others have had no difficulty assigning a finite and sometimes even negative value to the same resources. To illustrate, most gardeners do not usually perceive the wild relatives of crop plants that are growing in their lawn or tulip patch to be part of our "irreplaceable genetic heritage." They are weeds which have no value except possibly as mulch. Moreover, most gardeners will incur substantial costs, in money, time or effort, to be rid of them. In these circumstances, the these particular species have a negative value. (In effect, the gardeners would have to be paid to keep the weeds.) The point can be made another way: for many biologists the significance of the work of T.H. Morgan and others with the fruit-fly family Drosophilidae and particularly the species Drosophila melanogaster would be described as priceless. However, for horticulturalists whose crops suffer economic damage because of fruit-fly infestation, the species is a pest. Even

if they understand the biological importance of the fruit-fly family, they usually devote considerable effort and expense each year to crop protection.

It has always been difficult to ascribe a value to resources whic are "open access" or "public goods." This problem has been an important topic in economics at least since the Classical Economists such as Ricardo and Marx made the distinction between "value-in-use" and "value-in-exchange." This distinction is reflected in the water-diamonds paradox. Water is vital for sustaining life yet diamonds, which are not, have a higher market value than water. That is, water has high value-in-use but low value-in-exchange; vice-versa for diamonds. This paradox was resolved by the "marginalist revolution" of the neo-classical economists (Cournot, Walras, Mill, Pareto, Menger, and Marshall) who distinguished between the total utility of a resource and its marginal or incremental utility. A resource such as water can have a large total utility but a low marginal utility because (under most circumstances) it is not scarce.

The consequence of this marginalist approach is that the value of a resource is determined by its marginal utility; further, if markets operate relatively efficiently, this value is measured by its price. Economists have come to equate the value of a resource with its price. Indeed, shown in Hicks' Value and Capital (1946) and Debreu's Theory of Value (1959), two of the major works of economic theory over the last half century, value theory is price theory.

This simplification depends on the assumption that markets for all resources exist and function efficiently. The world, of course, is otherwise. Market fail because of external or spill-over effects, lack of information, uncertainty, and concentrations of economic power

(whether private or state). Under these circumstances, which are common, the private cost of the resources (as represented by the market price) is less than their social cost (as reflected in the best alternative use for the resources). This idea, which goes back at least to Marshall, was explored in detail by Pigou in The Economics of Welfare, and has been a central theme in the debate about the degree to which governments should intervene in the economic system (cf. Eckstein 1958; Samuelson 1958; Coase 1960; Turvey 1962; Davis and Kamien 1969; Schelling 1971; Mueller 1976; Wolf 1979). The debate played a major role in the development of social benefit-cost analysis with its various theories and techniques for deriving the social opportunity costs, or "shadow prices," of resources when markets do not exist or function poorly (cf. Prest and Turvey 1966; Mishan 1976; and Ray 1984).

Whether it is the adverse connotations of the term "shadow price" or simply that economists are pretending they can behave as if a market existed to determine the opportunity costs of resources, non-economists have been skeptical of social benefit-cost analysis. Oldfield's (1984:268-9) concern about the relevance of benefit-cost analysis for determining the economic value of genetic resources and habitats is widely shared (cf. Misra 1981; Norton 1985). She criticized the narrow range of criteria which are typically used in benefit-cost analyses of natural resources noting that the analyses are more frequently used to justify the development of biological resources rather than to ensure they are preserved.

The fourth interpretation of pricelessness is that a genetic resource has obvious biological value, but it does not have a market price. From an economic perspective, there is nothing unusual about

this. Many things have value according to a wide range of criteria yet do not have a market price: liberty, equality, justice, integrity, friendship, and honesty are examples. However, in order to enjoy or have them, individuals or groups within society have to use other resources such as time, skill, knowledge, physical facilities, and finance. That is, they have to incur a cost, which may or may not be measurable in money terms.

Some people have been prepared to incur potentially large costs. Patrick Henry's statement of "give me liberty, or give me death" to the Virginia Convention in March 1775 is well known.

The point is, contrary to Oldfield's (1984:267) assertion (quoted earlier), a resource does not need a market price to have economic value. It only has to be scarce so that the individuals or groups who value the resource will have to give up something, i.e. incur a cost, to have access to it. What they are prepared to give up is an index of its economic or scarcity value. By presuming that economic value is equivalent to a market-determined price, Oldfield has overlooked the concept of opportunity cost.[31]

A point worth noting from these two sets of examples is that the value of biological diversity depends on the particular context, namely who values it, how, when and why. What may be invaluable or priceless in one setting may be an expensive nuisance in another; and though a resource may not have a price in an organized market, individuals and groups may incur substantial opportunity costs to acquire or maintain.

4. Valuing Biological Diversity

a. Biological and Economic Perspectives

Two points stand out in the literature cited above. First, there are many criteria by which different individuals and groups value biological diversity. Second, the main justification for maintaining biological diversity rests on the technical concerns of preserving unique genetic information and sustaining the biotic systems which support human life. These points reflect the predominant concerns of the biological scientists who are so deeply involved in the issue. But, to generate and sustain the public and private support required to formulate and implement policies for maintaining biological diversity, a broader range of perspectives has to be considered. This requires a set of procedures for integrating both social and biologically relevant criteria. Doing this is not easy because there are significant differences between the perspectives of biologists an non-biologists as well as the criteria they believe are relevant. Th difficulties involved are both conceptual and methodological. To illustrate these points, we shall contrast the approaches of a biologist and an economist as "typical" representatives of biological science and social science.[32]

Conceptually, biologists and economists have different views of the world. Biologists, whose discipline is based on the laws of physics and genetics, tend to see the world in digital terms -- of limits, thresholds, and barriers. Economists, whose discipline focuses on individual and social responses to scarcity, tend to view the world in analog terms -- of incremental gains and losses expressed primarily in monetary rather than physical terms. To illustrate, for a biologist, a photon causes an electron to "jump" or it does not; a

nerve fires or it does not; a gene is suppressed or it is not; or a growth factor is limiting or it is not. For an economist, values are expressed in relative terms implying that there always is some degree of substitution between resources, and that, after allowing for different attitudes to risk and asymmetries in information, all scarce resources are used at levels where their value products are roughly equal. To illustrate, substitution can occur among the end uses of a resource or during its transformation, e.g. when the price of wheat increases relative to corn, less wheat is fed to livestock. It can also occur over time, e.g. when the price of wheat increases relative to corn, land is diverted from corn production to wheat. The value products (i.e. the physical output of a resource multiplied by its market or "shadow" price) are roughly equated across resources because people do not usually attempt to ruin themselves (Becker 1962). To survive economically, each person has to operate with an efficiency comparable to other producers in the particular economic system (Alchian 1950).

These differences are reflected in the methodologies members of both disciplines apply to resource conservation issues. While biologists focus on means of preventing a species, community or ecosystem from approaching its physical limits, economists focus on the social and institutional consequences of changes in the relative scarcity of resources.

These differences have meant that, with respect to the maintenance of biological diversity, biologists tend to leave off at the point where the economists start, and vice-versa. Biologists have typically shown little concern for the economic implications of their recommendations; economists have shown a similar disregard for the

biological consequences of their analyses. For instance, at the Strategy Conference on Biological Diversity (Dept. of State 1982), the focus was primarily on biological issues. The policy questions of what programs should be implemented, who would benefit from them and bear the costs, and who has to be involved and how if the programs are to be implemented received little attention (Lyman and McPherson 1981; McClintock 1982). This bias was unfortunate because generating and sustaining effective support for the maintenance of biological diversity is primarily a question of public policy.

For their part, economists have rarely considered the biological implications of the their assumptions. For example, Smith (1968), Clarke (1973), Plourde (1975), and Fisher (1981) all present models of resource conservation which takes the biological growth law of the species or the population as the logistic curve. None of them enquired about the relevance of this growth law; none analyzed whether the economically feasible rate of resource use each of them derived influenced the underlying pattern of species growth; moreover, none of them dealt with the problem of interactions among species. On the last point, as Levins (1968:Ch.6) and Beddington and May (1982) have shown, the logistic curve is a poor model of population growth when species interact. This result is well known to ecologists who have studied predator-prey interactions (cf.Ency.Britt.1974,vol.2:1046; Ricklefs 1979,Ch.8; Anderson 1981:70-82).

By contrast, biologists have emphasized the scarcity of biological resources and generally ignored the scarcity of other resources such as personnel, skills, finance and physical facilities. And, even when they have noted how the shortage of these resources have hampered their efforts, they have not systematically incorporated the effects

in their analyses (Marshall and Brown 1974; Hawkes 1983; Frankel and Soule 1981; Namkoong 1983). To illustrate, Marshall and Brown (1975) recommended a (.95,.05) rule for sampling crop germplasm. Their intention was to determine a sample size which, under conditions of neutral selection, would ensure that they had a 95 percent chance of obtaining all of the alleles with frequencies greater than .05 in the particular population. Frankel and Soule (1981:72-75) proposed a "basic rule of conservation genetics" designed to ensure that the inbreeding coefficient (the probability that two alleles at a particular locus in an individual are identical by descent) will change by no more than 1 percent per generation. These rules are based on the results of classical statistics and population genetics and some conventions accepted by biologists. They are not generally justified on economic grounds; indeed, the fact that these rules have economic implications has been overlooked.

The latter is a general problem: when resources are scarce, the benefits they provide, the costs that are incurred, and the selection criteria applied to them are interdependent (Thomas 1963). Only two of the three can be specified independently. For instance, if the costs of collecting germplasm are fixed because of a budget or time constraint, the specification of criteria to guide the collection activities, such as the (.95,.05) rule mentioned above, automatically determines the benefits expected from the collection effort. Whether these benefits exceed the costs so that the collection activities happen to be "economic" will depend on the characteristics of the population from which the material is collected.

The implication of this dependence of costs, benefits and selection criteria is that activities which may be justified in

biological terms may be unjustified economically. The process works in the other direction as well. When economists establish a benefit-cost ratio as their criterion of choice, the implied biological criteria will vary for each species or population. Again, what may appear to be economically sensible may be biologically senseless.[33] For example, when Hawkes (1971) recommended that crop germplasm must be conserved "at all costs," he was implicitly assuming that the benefits of ensuring that no germplasm is lost exceeds the cost (material, financial, time, and effort) that crop ecologists and others devote to the task. And, to those for whom crop germplasm is a priceless resource, the expected benefits of maintaining it are high enough to cover whatever costs are involved.

Biologists are not alone in ignoring the implications of their selection criteria. As mentioned above, economists frequently make the same mistake. For instance, the "safe minimum standard" of conservation proposed by Ciriacy-Wintrup (1952:Ch.18) is impractical The criterion is designed to avoid pushing a resource into its "critical zone" for survival, i.e. "...those physical conditions brought about by human action, which would make it uneconomical to halt and reverse depletion" (ibid.:253).

While the basic idea of not over-exploiting the resource is clear, the "critical zone" of a resource cannot be determined before the fact. There is a double-bind: the "critical zone" cannot be known until after the resource has been exploited to the point where it is uneconomic to reverse the rate of depletion; and if the resource is pushed to this point, the cost of reestablishing it will be prohibitive. Thus, the "safe minimum standard" is not a poor guide for determining the use of a resource. From experience, it has been

less than 50 individuals for the elephant seal (Wolkomir 1983); more than 2000 for the heath hen (Bachmura 1971); and less than 200 for the American bison (CEQ 1980:66).

Because of the double-bind, the general rule that Ciriacy-Wintrup (1952:259) proposed, namely that a "safe minimum standard of conservation should be realized with minimum total social costs" cannot be made operational.[34] The problem was not resolved by Bishop (1978; 1979) who proposed the modified minimax version of the safe minimum standard, namely that "...society should choose the safe minimum standard of conservation unless the social costs of doing so are unacceptably large. All Bishop did was to redefine the problem, from one of determining a safe minimum standard to one of deciding what level of costs society would bear to maintain particular populations or habitats.

Again the latter cannot be known in advance. Moreover, the amount society is prepared to bear is continually subject to renegotiation through the political process. Three examples are the beaver, the Minnesota wolf, and the pronghorn antelope (Hand 1984; Nevin 1985; Yates 1985). Conservation programs for these species have been so successful that there is mounting pressure for public action to reduce their numbers.

Some economists have circumvented the problems associated with the "safe minimum standard" by using the concept of "option value" (Krutilla 1967; Arrow and Fisher 1974; Fisher and Peterson 1976:2-3). They have argued that society (or a group or an individual) will incur a cost to retain the option to use or enjoy a particular resource at some future date. In this sense, the notion of "option value" is designed to take account of the asymmetries and irreversibilities in

certain types of economic activities. For example, the construction of a dam ("development") irreversibly alters a river and its associated habitats. The decision not to build the dam ("preservation") is a decision to retain the option to use the area as a habitat for rare species, for its scenery, for watershed management, or as the site of a future dam. Developing the dam, while creating other habitats and other types of scenery, forecloses the option of using the resource in its original state.

This idea of option value has support among conservationists and biological scientists. Frankel (1974:60) argued that preserving a wide range of crop germplasm allowed humans to keep their "evolutionary options open." (See also CEQ 1980; Wilkes 1983; and Oldfield 1984:Ch.1). In practice, there are difficulties raised by considerations of inter-generational equity and uncertainty. The inter-generational equity problem is that the current generation has to decide which resources it is prepared to pass on to future generations and to bear the costs involved. There are few rules. One guide is the objective, derived from Leopold's (1949) notion of "ecological conscience," that members of one generation ought to turn over the biological capital of the world to the next generation in at least as good a condition as it was passed to them (Cowan cited in Marine 1969:81). The problem in fulfilling this objective is that each generation leaves far more to succeeding generations than biological capital. The legacy includes knowledge, institutions, and productive capacity or more generally intellectual, social and physical capital. The dilemma for any generation is to decide on the mix of biological, intellectual, social and physical capital that it will pass on and what costs, in terms of lower living standards, it is

prepared to bear so that it can pass on this mix (Jones 1965; Plourde 1975; Bishop 1978; Miller and Menz 1979; Dubos 1980). Since this is not an issue which any generation will resolve once-and-for-all, it has to be the subject of continued debate and action as priorities are determined and the resources needed to make them effective are provided.

The second problem is uncertainty. The dimensions of future biological and social challenges are unknown so that it is not clear what mix of biological, intellectual, social and physical capital will best prepare the members of the next generation for the problems they will encounter. In deciding about these issues, the current generation is faced with two counteracting influences. Since the supply of physical resources are relatively plentiful (Goeller and Weinburg 1976; Simon 1981; Goeller and Zucker 1984), the prospects of continued global economic growth for the foreseeable future seem assured. Similarly, the prospects for the continued growth in knowledge appear bright. Therefore, the current generation can reasonably expect that most members of future generations will be richer and more knowledgeable and thus have a greater capacity to deal with their problems. The second factor is that decisions taken by the current generation will foreclose particular options for succeeding generations. The former works against preservation; the latter favors them.

In principle, these decisions are the same as those associated with any inventory of insurance problem, namely the net benefits of being "long" have to be weighed against the net benefits of being "short" (Arrow, Harris, and Marschak 1951; Smith 1968). The problem in maintaining biological diversity is to relate the reduction in

welfare experienced by the current generation, because of the resources (finance, time, skills, and physical facilities) devoted to preservation, to the likely costs imposed on future generations, in terms of its reduced ability to deal with its problems, because choices made by the current generation about preservation foreclosed useful options.

Though the formal structure of this problem is clear, dealing with it is not easy. Economists have provided few guides. Plourde (1970) circumvented the question of irreversibilities by restricting his analysis to the situation where the exploitation of the resource did not threaten its continued existence (ibid.:520). Arrow and Fisher (1974) argued that when the development of a resource is irreversible and has uncertain consequences, the optimal strategy is to under-invest in development in the current period. As more information accumulates, the under-investment can be remedied; initial over-investment cannot. Miller and Menz (1979) argued that wildlife is currently useful and, if preserved, has the potential to be useful for future generations. Brookshire, Randall and Stoll (1980) used a "total value approach" to show that the value of changes in the flow of natural resources will be bounded by the amounts people are willing to pay to increase the supply of the resource and the amount they will pay to avoid a reduction in it. Finally, Fisher (1981) noted that, because of market failures, economic models of resource use are biased toward over-exploitation. To compensate for the bias, he suggested (ibid.:16) that some non-extractive value be assigned to the resource.[35]

The above results are of little help to anyone who wants to determine how intensively a natural resource should be used. The

basic conclusion is that preservation gives future generations greate flexibility. This, of course, is a standard result of portfolio theory (Tobin 1965; Turnovsky 1972). Managing a portfolio is characterized by transactions costs (which are financial irreversibilities), adjustment lags (which are institutional irreversibilities), and uncertainty (resulting from asymmetries in th availability of information). To deal with them, portfolio managers typically diversify their assets in an attempt to spread risks and avoid positions which are difficult (if not impossible) to reverse. The literature above shows that these principles apply even to a "portfolio" of natural resources.

Thus, the same policy recommendation has been derived by both biologists and economists: because of irreversibilities and uncertainty about future biotic problems and changes in human values, a strategy for maintaining biological diversity is to retain a high degree of flexibility. For biologists, the strategy is to keep evolutionary options open; for economists, the strategy is to assign high option value to biological diversity. The problem with this recommendation is that it is an imprecise guide for policy. Flexibility is difficult to define: what is flexible to the point of lacking structure for one person may be rigid and unyielding to another. Moreover, the idea of retaining flexibility simply pushes the problem back another level. Since there are many biological and economic options available, the problem is to determine which of them should be kept open.

But, again we confront the problems associated with the different ways that biologists and economists view the world. For biologists, a flexible policy would imply a set of activities which avoid the limits

imposed by the loss of species and habitats; for economists, it would imply a set of activities derived from a comparison of the incremental costs of maintaining biological diversity with the incremental benefits. One way of resolving this problem is to develop a model which integrates the analytical approaches biologists and economists use. In this respect, information theory is the basic link.

b. Information Theory and Biological Diversity

The fundamental characteristic of biological diversity is genetic information. This information can be viewed at a number of levels: as linear sequences of nucleotides; as the sum of all the different alleles in a given population; as the dynamic pool of co-adaptive gene complexes in a community; or as the sum of all of the biotic interactions in a particular biome. The complexity increases at higher levels because of the additional information required to describe the relationships between the levels. The information content of biotic resources is large. A single cell contains on the order of 10^{12} bit (Ency. Britt. 1974, vol.10:894), and even the simplest living organisms have the potential to generate huge numbers of different genotypes. For example, the Moloney Murine Sarcoma Virus with 5828 base pairs in its genetic material (Reddy, Smith, and Aaronson 1981), has the potential to produce around 10^{3800} distinct genotypes. Given that there may be roughly 10 million distinct species on Earth and all higher organisms have DNA with base-pairs numbering in the millions and billions, the amount of genetic information in the biota is daunting.[36]

Though a potentially large amount of information exists, those concerned with maintaining biological diversity do not have to attempt to deal with it all at once. The relevant genetic in a particular

community is heavily "edited" through natural and social processes. From an evolutionary perspective, each species in the ecosystem has a limited number of genetic options. As Waddington noted (cf. Ency. Britt. 1974, vol.5:645), an organism's structure (which is genetically determined) simultaneously provides the potential for it to function in selected environments but severely constrains it from functioning in others. Gould (1980:40,45) made the same point when he observed that there are no morphological adaptations which will permit an elephant to fly. In addition, biotic interaction, especially of the type summarized by the principle of "limiting similarity" (cf. Gould 1980:48; Abrams 1983), restricts the amount of genetic information in a particular ecosystem even further.

From a social perspective, the genetic information is edited by the criteria individuals and groups use to value biological diversity. Economic criteria are particularly restrictive. Technically feasible options for preserving biological diversity are discarded unless they yield positive net benefits. This occurs because the collection, evaluation, and storage of germplasm or the maintenance of an ecosystem are costly activities. They require the direct and indirect use of physical facilities, financial resources, and skilled and semi-skilled personnel all of which have positive opportunity costs. Furthermore, for the purposes of maintaining biological diversity, attention only has to be given to rare and endangered species in the ecosystem.

Therefore, even though there is a large amount of genetic information in any ecosystem, much of it can be ignored. Morevover, since it is costly to collect and evaluate, most of it should be ignored.[37]

This information-theoretic model helps integrate the concerns of both biologists and economists. It allows the former to emphasize the types of genetic information that should be preserved to sustain crop and herd improvement and maintain the integrity of ecosystems; it allows the latter to focus on the relative costs and benefits of preserving biological diversity and the trade-offs which exist among the activities involved. Its main advantage, however, is that it is a useful way for each group to identify the various factors they feel are important for maintaining biological diversity within a consistent analytical framework. Furthermore, it helps make explicit the assumptions each of them makes and, in principle, provides a means of determining both the biological and economic implications of any criteria each of them uses.[38]

However, an information-theoretic approach is not a panacea. Like all conventional decision-theoretic models it presumes that the issues involved are subject to rational analysis and that both the perceived risks and preferences of those who are part of the decision-making process can be reasonably well represented. Moreover, it presumes that these individuals and groups are prepared to co-operate to formulate and implement a coherent strategy for maintaining biological diversity. The approach is most useful for dealing with issues that are readily quantifiable, for which reasonably consistent objectives can be determined, and which do not involve major changes in organizational structures to carry out the preservation activities.[39]

c. How Should the Value of Biological Diversity be Determined

There are no general rules for determining how biological diversity should be valued. Even if rules were derived, it is

doubtful whether everyone would agree with them or find it in their interest to adhere to them. Moreover, rules agreed to in one setting may not be acceptable in another. Hence, the relevant issue is not how biological diversity should be valued; rather, it is whether the values most people hold will ensure that a wide range of biological diversity is maintained. As with any other resource, the way biological diversity is valued depends on the perspectives of the individuals and groups involved; their preferences; their perceptions of whether the aspects of biological diversity they value are threatened; and what they are prepared to forego to ensure that the biological diversity they value is maintained.

Data on these points are available from the past and current activities of the individuals and groups who value biological diversity. They are especially useful in identifying the dimensions of biological diversity that are valued; who values them; and why. It is important to note that not only are these three (what, who and why) inter-related but the way they are related can change over time. An example will illustrate. In the story of Noah and the Flood, only organisms of the "flesh, wherein is the breath of life" (Genesis 7:12-24) were, at that time, considered worth saving. Plants were not included, an attitude that is unacceptable in among contemporary plant collectors, crop ecologists, plant breeders and hobbyists (Harlan 1970; Frankel 1974; Chang 1976;1984; Rockefeller Foundation 1980; Hawkes 1983; Swaminathan 1984; and Kahn 1985), most of whom would agree with Chang (1984:255) that "crop germplasm is surely one of man's most important biological treasures."

The evidence on what biological diversity is currently valued and by whom is rich and varied. In Table 1, I have assembled selected

examples in an attempt to summarize who has valued biological diversity and the dimensions of it they have valued. The data are arranged in order of descending generality and not, as noted below, in order of descending value.

Table 1: What Biological Diversity is Valued and By Whom

What is Valued	By Whom	Source
Rare Domestic Animals	Breeders, farmers, conservationists	Hickman 1982; Vietmeyer 1983
Animal Wildlife	Conservationists, breeders, herders	de Vos 1979; Miller and Menz 1979 Wolkomir 1983
Medicinal Plants	Research, business, public	Blair 1983 Oldfield 1984 Balandrin et al. 1985
Plants	Society, breeders, ecologists, collectors naturalists	Jenkins and Ayensu 1974; Elias 1983 Durant and Saito 1985 Richardson 1985
Nature/Wildlife	Ecologists, farmers society	Caufield 1981; Regan 1982; Aiken 1984
Species (Plants and Animals)	Mankind, breeders, ecologists, environmentalists	Bachmura 1971; Plourde 1975; Lovejoy 1976; Bishop 1978; Breach 1981; Harrington and Fisher 1982
Biological Diversity	Industrialists, ecologists, society, researchers, breeders, philosophers, farmers	Woodwell 1974; Eckholm 1978; CEQ 1980; Dept. of State 1982; Lewin 1984
Forests and Forest Habitats	Forest ecologists, goverments, commercial interests, community groups	NRC 1980; Barnard 1982 Omvedt 1984; Holden 1985; Norman 1985; Williams 1985
Crop Germplasm	Farmers, breeders, collectors, crop ecologists, botanists, society; evolutionary biologists	Frankel 1974, 1981; Harlan 1976; Wilkes 1977, 1983; NBPGR 1978; Mooney 1980; NGRC 1982; Plucknett et al. 1983; Hawkes 1983; Lyman 1984 Duvick 1984; Kahn 1985 Mooney 1985
Plant-microbe complex	Microbiologists, genetic engineers, plant breeders	Brill 1981; Rachie and Lyman 1981; Swaminathan 1983; Abelson 1985
Plant-insect complex	Entomolgists, society naturalists	Ehrlich and Raven 1967 Morse 1985
Plant-insect-animal complex	Entomolgists, ecologists, population biologists, breeders	McKelvey et al. 1981 Kolata 1984; Donelson and Turner 1985

Insect-animal complex	Microbiologists, entomologists, herders	Murray and Roelants 1979
Microbes	Genetic engineers, plant breeders, microbiologists, industrialists,	Dixon 1976; Berg 1981; Bodmer 1981; Abelson 1983; Cooney 1981; Swaminathan and Rao 1984; Jannasch and Mottl 1985
Microflora and microfauna	Ecologists, biologists, society	Pimental et al. 1980 Grassle 1985
Rice	Breeders, society collectors	Swaminathan 1984; Chang 1984; Kahn 1985
Maize	Breeders, society collectors	Griliches 1960; Wilkes 1983; Kahn 1985
Whales	Industry, ecologists, Governments	Clark 1973; CEQ 1980 Beddington and May 1983
California Condor	Ecologists, public, conservationists	Johnson 1983 Crawford 1985
Potatoes	Anthropologists, collectors, breeders, farmers	Brush 1980; Brush et al. 1981; Wolff 1983
Bald Eagle	Conservationists, farmers, government	Amacher et al. 1972
Minnesota wolves	Ecologists, public, ranchers, government	Nevin 1985
Parrots	Public, poachers,	Jackson 1985
Groundhog	Research, ecologists	Gilbert 1985
Mangroves	Ecologists, public, fishermen, seaside communities	Wiley 1985
Beaver	Government, public, resource scientists, environmentalists	Dubos 1980 Hand 1984
Elephant Seal	Coastal ecologists, government, public	Wolkomir 1983
Chimpanzees	Ecologists, social anthropologists, medical researchers	Ghiglieri 1985
Rhinoceros	Governments, poachers, public, biologists	Nickerson 1985
Butterflies and moths	Collectors, research scientists, society	Green 1985
Tasmanian tiger	Ecologists, hobbyists,	Park 1985
Puma	Conservationists, ranchers, geneticists	Parfit 1985

These data raise five points. First, no dimension of biological diversity is valued more highly than any other. To illustrate, though microbes are less complex than the higher plants and animals, they are highly valued by research scientists, ecologists, biochemists,

evolutionary biologists and the industrialists whose research, products and processes depend upon microbial action. Second, most of the authors cited have argued that non-specific entities like the public, society, and the government value biological diversity in general and selected aspects of it. This can be interpreted in two ways: many aspects of biological diversity are "public goods" which the public at large or society in general counts as part of its wealth; or it reflects the widely-held view that the public (or society or government) ought to value biological diversity.

Third, if the resources and time that have been devoted to preservation efforts are any guide, there are selected species and habitats that particular groups and individuals value highly. These include local forest habitats (Omvedt 1984), the California Condor (Johnson 1983), rice germplasm (Chang 1984), parrots and other exotic birds (Oldfield 1984:274-276; Jackson 1985), mangroves (Wiley 1984), white-tailed deer (Iker 1983) and Beavers (Hand 1984). Yet, contrar to the literature on the pricelessness of biological diversity, none of these species was assigned an arbitrarily high value.

Fourth, the adverse effects, or negative value, of particular dimensions of biological diversity were generally ignored. Thus, Dixon (1976:431) could argue that smallpox should not be made extinct because:

> the loss of any one species could be an appalling loss not only for studies in comparative biochemistry and genetics but also for fundamental work on the origin and nature of life

The implication is that, irrespective of how pathogenic any form of life is to humans, it should not be destroyed. This argument could also be applied to the organisms responsible for rabies, bilharzia,

schistosomiasis, malaria, river blindness, botulism, meningitis, and yellow fever which with others have made human existence more varied though more tragic (Webbe 1981; Gilles 1981; and Foulkes 1981). Given the misery these organisms have caused, I doubt that many members of the general public would share such a narrow scientific view (cf. Goodfield 1985).

This bias against dealing with the adverse effects of biological diversity is illustrated in other ways. Though some authors have discussed the problem of "biological pollution" caused by the introduction of exotic species into new habitats (cf.CEQ 1980: 61-64), the literature cited so far has not addressed the issue of economically undesirable biological diversity. For instance, the annual expenditure by U.S. farmers on herbicides and other pesticides is from $5 to 6 billion (Agricultural Outlook Oct.1983:22).[40] Since farmers do not intentionally lose money, they must estimate that it is worth at least this amount to reduce the effects on their crops and livestock of undesirable biological diversity (Boyer 1982).[41]

Fifth, this literature has only just begun to touch on the problems of conflicting values (Aiken 1984). These conflicts occur at several levels. Two have already been noted. Some scientists wish to preserve all species for continued research whereas most members of the public would prefer to have selected species wiped out if it were possible.[42] Ecologists and conservationists want to ensure that biological diversity is preserved, a goal which most farmers share providing the biological diversity in question does not cause them economic losses.

Another conflict exists between the goals of biological scientists to preserve landrace and traditional species of crop plants and

livestock and the desire of farmers (particularly those in developing countries) to increase their incomes and standards of living. There have been many references to the genetic erosion caused by the introduction of improved cultivars and strains of livestock (Miller 1973:1232; Mooney 1980:12; Hickman 1982; Vietmeyer 1983; Hawkes 1983:109; Chang 1984:252). This literature, however, has generally given a lop-sided view by focusing on the costs (namely genetic erosion) and giving too little attention to the benefits (higher productivity, increased rural incomes and relatively cheaper supplies of basic foods). The image that Wilkes (1977) evoked when he argued that genetic erosion is the same as using bricks from the foundation to build the roof has tended to dominate the discussion of the issue (cf.Mooney 1985). Among those cited in this study, too few have given much weight to the positive results when farmers replace their traditional cultivars and livestock strains with improved ones.[43]

The conflict in values is clear. Many farmers and poor consumer have benefited significantly because scientists have increased crop and livestock production through selectively narrowing the genetic bases of the major crop varieties and strains of livestock. To admit these benefits does not deny or diminish the costs involved (genetic erosion and genetic vulnerability) it simply makes the point that the costs have not been incurred in vain.[44]

d. Policy Formulation for Maintaining Biological Diversity

Formulating and implementing effective policies for maintaining biological diversity require some guiding principles. These include: (i) from the start, clear objectives for the policies should be stated; (ii) as broad a degree of participation as possible in policy formulation should be encouraged; (iii) policymaking should be a

dynamic adaptive exercise; and (iv) there should be a commitment by those involved to improve the process by which the policies are formulated.

A clear statement of objectives is needed because any policy exercise is essentially an attempt to resolve the question: who has to what, when, how, where, with whom and for whom to achieve the particular objective (cf.Boulding 1958; Griffen 1973). Without some notion of the policy's goals, this question cannot be answered.

A variety of skills or capacities are needed to deal with this question (Mann and McPherson 1985): strategic capacity, which is the ability to place an issue in a broader context; administrative or managerial capacity, which is the ability to draw together the individuals and groups who are relevant to the particular policy; technical or analytical capacity, which is the ability to clarify or elaborate specific aspects of the issue; and, communication skills which enable an individual to share ideas and information with people from a diverse range of backgrounds.

Since few people develop all of these capacities equally, one reason for encouraging broad participation in the policy process is to ensure that individuals who have them are involved. Another reason is that the problem of maintaining biological diversity cannot be addressed effectively along narrow disciplinary lines.

This is where the information theoretic approach is a useful. Because it provides a common conceptual framework for both biologists and economists, it encourages interdisciplinary communication. Once the biologist begins to understand the economist's view of the world and vice-versa, his/her perspectives begin to broaden. For example, as work together, the economist will discover that the concerns of the

biologist are solidly based on the fundamental principles of physics, ecology and genetics. He/she will learn that there are some biological limits that do matter and, for any economic analysis to make sense, they have to be taken into account. Similarly, their joint work will increase the biologist's appreciation of the economist's focus on the problems of social choice. From this, the biologist will learn that the notion of opportunity cost is pervasive and, for his/her biological analysis to have policy relevance, has to be addressed.

Broad participation in the policy process has both positive and negative dimensions. The more who participate, the greater the chance that the policies actually formulated will be effectively implemented. Broad participation provides the opportunity for both opponents and proponents of the policy to share their differences so that most of them can be resolved, or, rather, an outcome can be derived that the parties involved can "live with." Finally, since biological diversit is valued in so many ways by so many people, broad participation in the process has to occur if the exercise is to be politically acceptable.

The disadvantage of broad participation is that it is more difficult to achieve agreement on specific goals. There is also a greater chance that coalitions can form to divert, delay or disrupt the policy process in the hope that the views of their members will be favorably considered (Schelling 1960:Ch.4; Ilke 1973; and Hamburger 1979).

These strategies are common to the policy process. It is tempting to minimize their effects by restricting the number of participants in the exercise. But, to exclude groups because their attitudes and

behavior are incompatible with the "broad consensus" makes the mistake, in my view, of placing the need to have a policy ahead of the policy objectives.

The overall goal is to maintain biological diversity. Many of the threats to biological diversity which now exist are the result of the ability of someone or some group to gain a short-term (private) advantage at the cost of longer-term biotic degradation. Thus, it is precisely the type of people who are likely to drop out of the policy process first who are the ones who, if the goal of maintaining biological diversity is to be achieved, should be included.

Encouraging these groups to become involved and keeping them involved is not an easy task since, for them, cooperation is a dominated strategy (Hamburger 1979). Nevertheless, attempts have to be made to work with them. This is where strategic capacity and communication skills are so important. The former to be able to put the reasons for their non-cooperation in perspective and the latter to find means of effectively engaging their attention.

To illustrate, one group that will be particularly difficult to involve are those who, for religious or spiritual or philosophical reasons, believe that existence is the only source of value or who treat biological diversity as being priceless. It will take great skill to have these people feel that they can be part of a policy process which by its very nature is to determine priorities and derive relative (and not absolute) values. Choices have to be made because, as noted earlier, resources of all kinds, and not just biological diversity, are scarce. As recent examples have shown (Ruckelshaus 1983; Kolata 1985; Sun 1985; Koshland 1985), there are so many difficulties having groups whose views are less polarized cooperate.

Whether those whose values greatly diverge from the norm, or whose interests are in conflict with the goals of the policy, can be encouraged to participate is an open question.

The third guiding principle for policy formulation is that it should be adaptive. A major mistake is to give undue attention to consistent behavior, especially over time. Because humans learn, consistency cannot be treated as a major constraint to action. As circumstances change or new information arises, both attitudes and opinions have to change if those involved in the policy process are committed to learning and not simply the promotion of a set of preconceived ideas (Weiner 1967; Day 1976).

The basic idea is that the policy formulation and implementation should, in addition to being an opportunity to respond to a pressing social concern, be an opportunity for social learning. Each of us has a relatively limited amount of information about the various aspects of our biophysical and biosocial settings. Furthermore, we are uncertain about the future and not sure how much of our accumulated experience is a relevant guide to it. To learn more and to begin to come to grips with the uncertainties involved, we require an adaptive approach that draws on the perspectives and experiences of others.

The fourth principle is that those involved in policy formulation should be concerned about improving the procedures and processes whereby policies are derived. This longer term focus explicitly recognizes that the problems of maintaining biological diversity are dynamic; they can rarely (if ever) be resolved once-and-for-all especially in a pluralistic society; and the perceptions created by the policy formulation in one period can have an important impact on the expectations and support generated for the process in a future

period.

This is where I see exaggeration to be so counter-productive. In the current period, exaggerated claims may be persuasive and policies for the maintenance of biological diversity may be based on these claims. But, as the exaggerated claims are proven false over time, there is an erosion of public confidence and support. Since the maintenance of biological diversity is a long-term problem, those involved in the policy process require the patience and foresight to forego apparent short-term advantages, especially if, as in the case of exaggeration, these undermine the longer term goal.

5. Summary and Concluding Observations

This essay has critically reviewed expressions about the value of and concern for the maintenance of biological diversity. These issues are not easy to place them in perspective: biological diversity that one person may describe as priceless could be a pest to someone else; and what some people may see as impending biological disaster, others may treat as unscientific nonsense.

These differences in values and concern reflect different interpretations of the available evidence; a lack of information (or a misunderstanding) about the threats to biological diversity; an ideological commitment to a particular view of the world; or differences in religious or philosophical attitudes about mankind's responsibilities for the biota.

The principal conclusion of this analysis is that there are many values of biological diversity, none of which so far has transcended the others. Who values what aspects of biological diversity, how and why, depends on the specific context.

Therefore, if a general policy for maintaining biological diversity is to be formulated and implemented some means have to be found to combine the perspectives of those whose values matter for the policy and to devise procedures for mediating their concerns.

To deal with the first point, I suggest using an information theoretic model because it highlights the broad similarities between the conceptual framework used by social scientists and biological scientists in their analyses of biological resource issues. For the former group, the model provides a means of identifying the social costs and benefits of maintaining biological diversity and systematically comparing them. For the latter, it leads to a set of procedures for determining the types of biotic information that are required to devise and implement programs for maintaining biological diversity.

To deal with the second point, I argue that because of the public nature of the task of maintaining biological diversity, there should be centralized leadership to coordinate the efforts of the many people who value biological diversity and are prepared to devote their energy to its preservation. The challenge is to direct this concern and energy in a ways that serves the larger goal of maintaining biological diversity.

The idea is to begin from the proposition that no single group can command the support to maintain all the biological diversity it values. Cooperation and compromise, based on the willingness of those who value biological diversity to expand their views of the world, has to be encouraged if the broader goal of maintaining biological diversity is to be achieved.

Footnotes

1. This applies to the notion of "intrinsic value," which is the value of biological diversity independent of human actions or concerns. In this case, the context is the set which is free of all human values.

2. Zuckerman (1973:139) referred to arguments in the Limits to Growth study as "unscientific nonsense" because they dealt with the effects of increased resource use independently of the growth of human knowledge. Frankel (1981:209-213) labeled Mooney's (1980) assertions about how Plant Breeders Rights deprived poor countries of their germplasm as "unadulterated nonsense."

3. This point was illustrated by the reviews of this paper. The following are samples:

i. I like the way this paper puts things in proper perspective.

ii. This is a very bright, well-written, well-documented, and stimulating paper.

iii. If you paid money for that study, you're trying to compete with the DOD in the $7,000 hammer league -- at least the hammers they buy can drive nails.

iv. McPherson's ecological conclusions are scientifically unwarranted, and insofar as they will lull the lay reader into a false sense of security, dangerous. Moreover, his faith in technology as a cure-all for the few problems he does perceive is outdated and pathetic.

Taken together, the reviews demonstrate the basic points I make in this essay: there is such a range of opinions about and attitudes towards maintaining biological diversity that no single group has a sufficiently compelling set of arguments for ensuring that the biological diversity it values will indeed be preserved. The challenge is to devise procedures which can integrate these diverse perspectives so that a coherent set of programs for maintaining biological diversity on a sustained basis can be formulated and implemented.

4. This paper identified three reasons why people exaggerate when they offer policy advice. One, they lack the information needed to put the issue in perspective. Two, they use an inappropriate methodology for evaluating the issue. A common problem here is "speciously accurate" data (Morgenstern 1963). Three, they exaggerate for ideological or political purposes. Sometimes the arguments are propaganda, deliberately intended to mislead the audience (Doob 1966:Chs.11-17). Or else, the people involved are so convinced that they are right they exaggerate in an effort to share their "truths" with others (Eccles 1970:114).

5. Dealing with rhetoric in a serious way is difficult. For instance, the exchange between Simon and several others in Science following his rejection of "false, bad news" (Simon 1980) shows that few, if any, people consider their points of view are exaggerated. It also showed the thin line between rational discussion and rhetoric.

Simon, himself, confused the issues with exaggeration of his own (regarding the availability of copper in the Universe, and the specious accuracy of some data he cited cf.ibid.:1432, 1435-6). This allowed those he criticized to deflect attention from the main point of the debate: whether the evidence on population, food and the environment is being interpreted too pessimistically. This issue remains unresolved.

6. The reverse dilemma also applies. Those who do not exaggerate risk making a reasonable argument that is either swamped by the noise of other arguments or is passed over because it appears mundane. Those who feel uncomfortable intellectually with exaggeration, but who want their opinions considered, seem to have three options. One is to align themselves with a group that has access to policymakers. A second is to continue their work, jointly or alone, secure in the knowledge that as Keynes (1936:383) suggested, the power of [reasoned] ideas is ultimately more potent than vested [or exaggerated] interests. A third is to recognize that the very nature of the problem of maintaining biological diversity, requires cooperation and compromise if effective programs are to emerge. The process of reaching a compromise will tend to diminish the impact of exaggerated notions.

7. Russell (1959:15) argued that:

> A scientific opinion is one which there is some reason to believe true; and unscientific opinion is one which is held for some reason other than its probable truth.

The same point was made by Passmore (1978:20) who noted that the difference between science and occult is that "science leaves a great deal unexplained." For Ehrlich, nothing was left unexplained: hundreds of millions of people would starve.

8. One reviewer of this paper noted that "to ridicule Ehrlich, Carson, Lovejoy, Myers, et al. as scientists because of the broader concerns they address and disseminate in the lay literature is disrepectful." Two comments seem relevant. Firstly, the criticism in this paper is not intended as ridicule. I give reasons for my criticism and provide references which may be easily checked. Secondly, whether they specialize in the study of physical or social phenomena, I believe that scientists should have a reasonable regard for the process by which knowledge is accumulated. That is, a scientist should maintain the same commitment to truth when addressing a "lay audience" as when he/she is subject to peer review in his/her own discipline. The "lay audience" deserves no less. That many scientists have done otherwise is, in my view, where the disrepect exists.

9. Any attempt to fully understand the biophysical setting encounters the problems of the physical and mental limits of our perceptions. In physical terms there is the Heisenberg Uncertainty Principle which limits our ability to ever fully describe the state of any system (Russell 1959; Bronowski 1978). Our mental limits have a number of sources. One is that our physical capacity to perceive our

surroundings is limited (McKay 1969; Bateson 1979). A second is that what we perceive is largely conditioned by what we expect to perceive. As Chambers (1981) noted there are questions we do not ask, connections we do not make, and relationships we do not consider. A third is that no single individual has all of the relevant information to deal with any social problem (Hayek 1945). And, a fourth is that because it is costly to assemble and analyze information, it never pays us to be "fully" informed (Dillon 1971; Arrow 1974).

10. The world is a poor place. To illustrate, in 1982 total world GNP was approximately $13 trillion. Since the population was roughly 4.6 billion, average per capita income was $2800. While this average shows that by and large people are not well-to-do, it disguises the essence of the poverty problem, namely that the distribution of world income is highly skewed. The rich countries (both East and West) had around 28 percent of the world's population and generated about 80 percent of the world's income. That is, the rich countries had per capita incomes of just over $8000 while the poor countries had per capita incomes of just under $800. But even these data give a false impression. China and India together had 38 percent of the world's population and generated 4 percent of world income. Their average per capita income was $300. (The data come from the Handbook of Economic Statistics 1983 and the IMF Year Book 1983.)

11. There is a striking similarity between this argument and the Limits of Growth study (cf. Meadows et.al. 1973). For instance, the latter concluded that the current trends of resource use would lead the Earth to its physical limits within a century. This would precipitate "a rather sudden and uncontrollable decline in both population and industrial capacity" (ibid.:23). Like the Limits study, Oldfield also ignores the growth in knowledge that will accompany the increased resource use.

12. One reviewer commented that my interpretation of these data was "pollyannish." We simply could have different interpretations of the term "massive." Another reason, perhaps, is that while I hope that no biological diversity disappears needlessly, I attach little weight to the idea of "existence value" (cf.Ehrenfeld 1976:654). Of course, for those who do, any loss of biological diversity is "massive."

13. Satellite sensing techniques combined with on-the-ground surveys are significantly improving the ability to map changes in forest cover (cf. Tucker, Townshend and Goff 1985). These techniques may have the effect of focusing attention on areas experiencing the greatest environmental pressure (such as parts of Sub-Saharan Africa) and perhaps encourage international efforts to deal with the principal causes (such as poverty and inequality).

14. Oldfield's (1984) response to the question "Are living resources becoming scarce?" reflects this attitude (ibid.:286):

> ...it is likely that the answer would be "possibly" from the standpoint of the conventional resource economist, "probably" from the worldly-wise, environmental economist, and "definitely yes" from the international conservationist who is fighting

the losing battle of salvaging portions of the gene pool resources of an ever-increasing number of vanishing life forms.

15. The following two quotes summarize this view. A National Board for Plant Genetic Resources (NBPGR 1978:1) report noted:

> ...the population is predicted to reach 6 to 8 billion by the end of this century. If the human family expects to feed its burgeoning numbers, there must be a 90 percent increase in food production by the year 2000. During the same time, hundreds of thousands of plant and animal species will become extinct if present erosion is not halted.

The Council on Environmental Quality report on biological diversity (CEQ 1980:34) observed:

> In the next 20 years, the human population is expected to swell nearly 50 percent and, in some of the poorest countries, nearly 100 percent. Demands on living resources will increase rapidly. To avoid worldwide deterioration in the human condition, food yields in traditionally harvested lands and waters must keep pace or new areas must come into production. Neither alternative will be readily accomplished. With present agricultural practices, increases in yield per acre are ever more costly, even where productivity of the land is maintained. Too often it is not -- because of desertification, salination, erosion, urbanization, or pollution.

16. Ehrlich and Ehrlich (1970:1) described the relationship as follows:

> The explosive growth of the human population is the most significant terrestrial event of the past million millenia. Three and one-half billion people now inhabit the Earth, and every year this number increases by 70 million. Armed with weapons as diverse as thermonuclear bombs and DDT, this mass of humanity now threatens to destroy most of the life on the planet. Mankind itself may be on the brink of extinction; in its death throes it could take with it most of the other passengers of Spaceship Earth. No geological event in a billion years--not the emergence of might mountain ranges, nor the submergence of entire subcontinents, nor the occurrence of periodic glacial ages--has posed a threat to terrestrial life comparable to that of human overpopulation.

17. This theme recurs in the writings of other Classical economists

(cf.Engels 1971:Ch.V).

18. Bennett (1954:52) stressed this point when he argued that to treat population as exogenous was to forget that:

> ... man is unlike animals and insects in that he produces food for himself by his own efforts, and is not merely a gatherer of what nature puts before him.

19. There are several reasons for this shift. First, it was realized that the rapid industrial expansion in many poor countries in the 1950s and 1960s did little to promote employment and adversely affected the productive capacity of agriculture. Second, the world has the physical resources to produce many times the available food supply (cf.Mather 1964:309-311; Revelle 1976) but that large numbers of people are too poor to buy additional food even if it were available. This has been confirmed by Sen's (1980;1981) work on famines and India's recent food surpluses. Famines occur and the food surpluses exist in large part because of poverty (cf.Ram 1982; Dogra 1985). Third, development specialists now understand that for significant progress towards alleviating poverty, attention has to be focused on the rural areas. For the present, this means sustaining agricultural growth rates in Asian countries, and a major effort to revive the agricultural sector in most countries of Sub-Saharan Africa. Both will require the maintenance of biological diversity.

20. Eckholm (1978:18) argued:

> No one could claim that all existing species are ecologically essential to the viability of human culture. But scientists cannot say where the critical thresholds lie, at what level of species extermination the web of life will be disrupted.

21. One reason for this conclusion, which is more evident in Frankel (1983) and Soule (1983), is that the objective of long-term preservation is to ensure that species will continue to evolve. For many species, these conditions exist whether humans interfere or not. But, for others, human interference has foreclosed this prospect. Frankel and Soule (1981) chose to emphasize the latter.

22. Though technical sophistication has increased the destructive power of humans, even their mundane activities have caused extinctions. For example, St. Stephen's wren became extinct when a light-house keeper brought his cat to the island where the flightless birds lived (Wolkomir 1983).

23. Many people would argue that the major threats to life are not biophysical problems, such as species loss and environmental degradation, but social problems such as poverty and nuclear proliferation. These arguments appear in several forms. Zuckerman (1973:147) believed that "environmental problems are more manageable than social and political problems." Stebbins (1977:252) argued that the future is "destined to be dominated by the cultural evolution of

mankind." Like many others (Frankel 1974; Bronowski 1978:148; Bateson 1979:Ch.1; and Brown et al.1985:Ch.1), he worried that science and society were "out of joint" -- that the social capacity to create institutions which keep the forces of technology in check are too weak.

24. An interesting observation on the psychology and economics of potential disaster is that in recent genetic disasters -- the wheat rust of the 1950's, the Southern corn blight in 1970, and the brown plant hopper infestation of the early 1970's -- all of the major actors, from farmers and seed distributors, to research scientists and geneticists, knew of the problems well in advance (Wilkes 1983:139; Scheffer and Livingston 1984:18-19; and Chang 1984:254). This is contrary to the general impression in the literature and the popular press (Mooney 1980; Harley 1981). Though some individual folly may have been involved, it is clear that the farmers, seed distributors and breeders thought that the risks of continuing to use the susceptible crops were within acceptable limits.

25. Bodmer (1981:314) suggested that the number is on the order of 10^{10000}. By comparison, the number of particles, the size of a proton in the observable universe is about 10^{125}.

26. Hawkes (1983:78) cited earlier work by Allard that noted "each species contains millions, or even hundreds of millions of variants.

27. DiBerardino et al. reviewed evidence for the "genetic multipotentiality" of selected species and concluded (ibid.:951):

> Continued investigations in living experimental systems leading to the activation of dormant genes may uncover greater genetic potential than already observed.

28. Both the NAS and Rockefeller missions noted:

> For thousands of years Chinese peasants have selected their crops for adaptation, disease and insect resistance, and the ability to produce despite adverse weather conditions, floods, droughts, and low soil fertility. The result is a priceless heritage of indigenous germplasm consisting of locally adapted, variable landrace populations of many species.

Eckholm (1978:12) observed:

> Since the impending large-scale loss of species is without precedent and involves the disruption of ecological systems whose complexity is beyond human grasp, no means exist for quantifying the costs. But to be without a price tag is not to be without value. The biological impoverishment of the earth will certainly contribute to the economic, let alone the esthetic impoverishment

of humans. And what is irreplaceable is in some sense priceless.

29. One reviewer noted that there were other logical possibilities. For instance, a resource could be priceless because it has infinite value; or it has a value for which a person would exchange all his/her wealth; or it has a value which a person refuses to discuss in money terms; or it has no ascertainable price (though it may or may not be of value to the person). Another possibility we both missed is a person values the resource so highly that he/she believes others should devote their wealth to preserve it.

30. They may have expected their audience to discount the statements appropriately. Donleavy (1984:151) made the point well when he noted "of course I exaggerate for the sake of accuracy. Knowing that anyone listening to what I'm saying will take it with a grain of salt."

31. One reviewer commented that I "seem to slip between value and economic value, as though all values are economic values." He/she continued: "when Patrick Henry prefers liberty over death [sic!], and incurred or would have incurred some "costs" (time, effort, money, pain) to defend his convictions, do such "costs" indicate the economic value and therefore the total value of his convictions?" The answer is no. The economic value of Patrick Henry's convictions are represented by the scarce resources (time, effort, skill, and his life) that he was prepared to use defending them. This, however, is not the total value of his convictions. At the time, they were of inspirational, patriotic and perhaps religious value as well. Over time, they have come to have historical value.

32. This focus is for convenience only. Readers may wish to repeat the exercise by contrasting the basic world views of say an ecologist and a sociologist, or an evolutionary botanist and an anthropologist, or a geneticist and a political scientist.

33. This interdependence among benefits, costs, and selection criteria is a feature of duality theory (Samuelson 1971). In principle, every optimization problem (such as choosing the number of samples from a neutrally selected population required to satisfy the .95,.05 criterion) has two parts, a 'primal' and a 'dual'. In the discussion above, the 'primal' is the problem of minimizing the number of samples needed to satisfy the (.95,.05) criterion; the dual is the problem of maximizing the benefits of satisfying this criterion subject to the limits imposed on collection activities by the available resources.

34. The problem with the "safe minimum standard" is that it attempts to simultaneously minimize two function, safety and social cost. This is not possible given the structure of both of these functions. The former is positively related to the number of individuals in the target population while the latter is negatively related to it.

35. Oldfield's criticism of the narrowness of economic analyses of resource issues (noted earlier) is well-founded. For example, in their discussion of resource economics Cramer and Jensen (1985:Ch.11) begin by noting (ibid.:259)

> Natural (or other resources) in themselves, have no value; they are valued and command a price, only because they are capable of producing goods and services people want and are willing to pay for.

Summarizing this point later they state (ibid:279): "a natural resource has value only when an economic use has been discovered for it." Such a narrow perspective partially justifies the low regard many biologists have for economists and economics.

36. Recently, geneticists have focused on larger units of genetic information, such as the "gene cluster" (Bodmer 1981:315-320) or the "structural functional loci" (Soule 1983 127-9). Even with these units, the amount of genetic information in any ecosystem is still large. However, these units are relevant to selected genetic problems. Many biologically and economically important genetic changes consist of single base substitutions. Herbicide resistance (Marx 1983; Erickson et al. 1985) and shifting biotypes malaria parasites and trypanosomes (mentioned earlier) are examples.

37. These species will not be ignored forever. Decision-makers will normally update their assessments of the situation as more information accumulates on, for example, species rareness, changing environmental pressures, and shifting pest populations (Dillon 1971; Day 1976).

38. The model is outlined in Lyman and McPherson (1982) and discussed in detail in McPherson (1985). It draws on the formal similarities between the activities of collecting, evaluating, storing and using genetic information and the collection, analysis, transmission and interpretation of other types of information. It is primarily designed to integrate the perspectives of both biologists and economists though it can be more widely applied to other biological and social scientists. Biologists contribute by evaluating the existing status of particular types of genetic information; indicating what biological risks exist in the foreseeable future; assessing whether the available genetic (and other types of) information are adequate to respond to likely future problems; and identifying relevant criteria for the collection and evaluation of genetic material. Economists contribute by indicating some of the social dimensions of activities associated with genetic information; estimating the costs and benefits of these activities; translating some of the risks perceived by biologists into terms amenable to policy analysis; and examining alternatives for effectively using the resources available for collecting, evaluating, and storing genetic information.

39. These are typical limitations of benefit-cost analysis. Though these limitations exist, whenever resources are scarce the use of a benefit-cost framework is inevitable. For example, the concept of "ecological efficiency" which is the percentage transfer of energy from one trophic level to another (Ricklefs 1979:783-5) involves the comparison of the output of energy at one trophic level (the benefit) with the input of energy (the cost) at another level. Some authors mistakenly presume that benefit-cost analysis is confined to economics (cf.Oldfield 1984; Norton 1985).

40. In 1985, U.S. farmers are expected to use between 430 and 470 million pounds (active ingredient) of herbicide and between 64 and 70 million pounds (active ingredient) of insecticide on the major row crops, barley and rice. The cost of the former will be approximately $1.8 billion; the cost of the latter approximately $.7 billion (cf. Agricultural Outlook March 1985:20; May 1985:22.)

41. While farmers attempt to reduce the incidence of species which reduce the productivity of their crops and livestock they have also recognized the problems arising from excessive use of pesticides. In the developed countries, this recognition owes much to Carson's Silent Spring. A greater sensitivity to the problems has emerged in developing countries as well. The resurgence of malaria in Central America and South Asia (Chapin and Wasserstrom 1981; Gill 1985) has highlighted the problem. Farmers have responded by shifting to integrated pest management (McKelvey et al.1981,Pt.IV; Crosson 1983; Agricultural Outlook Oct.1983:22-23; Aldrich 1984).

42. The chance of wiping microbes out is low, but their incidence can be reduced. Most people would agree that the smallpox eradication program has been worthwhile. The disease may recur in future generations, nevertheless the current generation has been spared considerable suffering.

43. Though there are many references to Green Revolution varieties displacing local cultivars (Miller 1973:1232; Frankel 1974:55; Wilkes 1977:12,1977:313; Mooney 1980:12; Brush 1980:164; Pearse 1980:Ch.2; Walsh 1981:161; Hawkes 1983:109), too few have mentioned how limited geographically the Green Revolution has been. Shifting cultivators have benefited little if at all (Greenland 1975), and its impact on secondary or marginal areas has been small (Ruttan 1977; Koppel 1981; and Chang 1984). The lack of success of high-response varieties in many areas has shifted agricultural research priorities in directions that favor the maintenance of biological diversity. This research seeks to recreate and maintain as wide a range of species diversity at the farm level as possible. It has been stimulated by the recognition in the international agricultural research community that a major long-term effort will be needed to produce the equivalent of a green revolution in Africa (World Bank 1984:Ch.3; Brady 1985; Mellor 1985). Positive developments in this area are: (i) the focus on farming systems and agroforestry research which highlight the importance of crop and livestock diversity; and (ii) the cooperation among African countries in germplasm collection and exchange (Hanson 1979:Ch.8; Bayliss-Smith 1982; Eicher and Baker 1982; Raintree 1983; Mooney 1985)

44. There has been much adverse comment about the narrow genetic bases of the major cereal crops. Frequent comments are: (i) only a small number of varieties are currently grown; and (ii) that many of the elite lines used are highly inbred (GAO 1981; Porter and Smith 1981; Smith 1982; Wilkes 1983). Though most observers have viewed this situation negatively, it is clear that the major crops have been dramatically improved using only a fraction of their genetic potential. For this reason, I believe that much of the concern about the narrow genetic base of crop plants has been misplaced. So long as breeders and farmers remain attentive and respond to shifts in the

biotypes of pests and pathogens, the risks associated with using only few varieties of each crop will be limited. Besides, the genetic bases of most of the crops which have had a major impact internationally have not been narrow (cf.Dalrymple 1979; IRRI 1980). For instance, IR36 is the result of crosses among 13 varieties from 6 different countries. And, in the U.S. where the concern about the narrowness of elite lines is so often expressed, breeders have broadened the genetic bases of the major crops over the last 15 years (Duvick 1984).

Bibliography

Legend

AAAS	American Association for the Advancement of Science
ATAS	Advance Technology Alert System
CEQ	Council on Environmental Quality
CGIAR	Consultative Group on International Agricultural Research
Ency.Britt.	Encyclopaedia Brittanica
FAO	Food and Agricultural Organization
GAO	General Accounting Office
IBPGR	International Board for Plant Genetic Resources
IMF	International Monetary Fund
NAS	National Academy of Sciences
NBPGR	National Board for Plant Genetic Resources
NCGR	National Council on Gene Resources
NRC	National Research Council
OECD	Organization for Economic Co-operation and Development
ODI	Overseas Development Institute
USDA	United States Department of Agriculture
USDOI	United States Directorate of Intelligence

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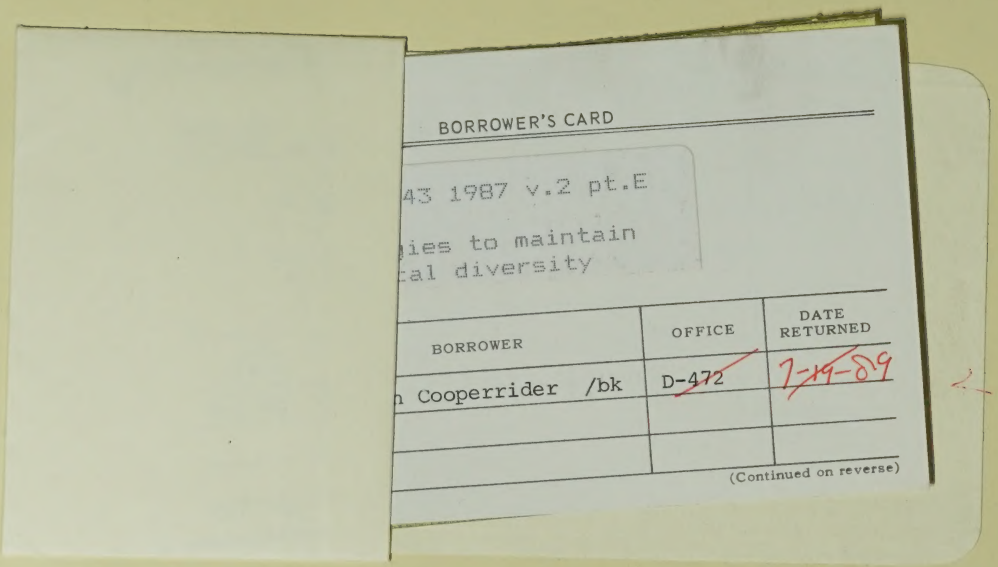

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